DC Solid State Transformer Based on Series-connected SiC MOSFETs

Shuai SHAO
College of Electrical Engineering
Zhejiang University
Hangzhou, China

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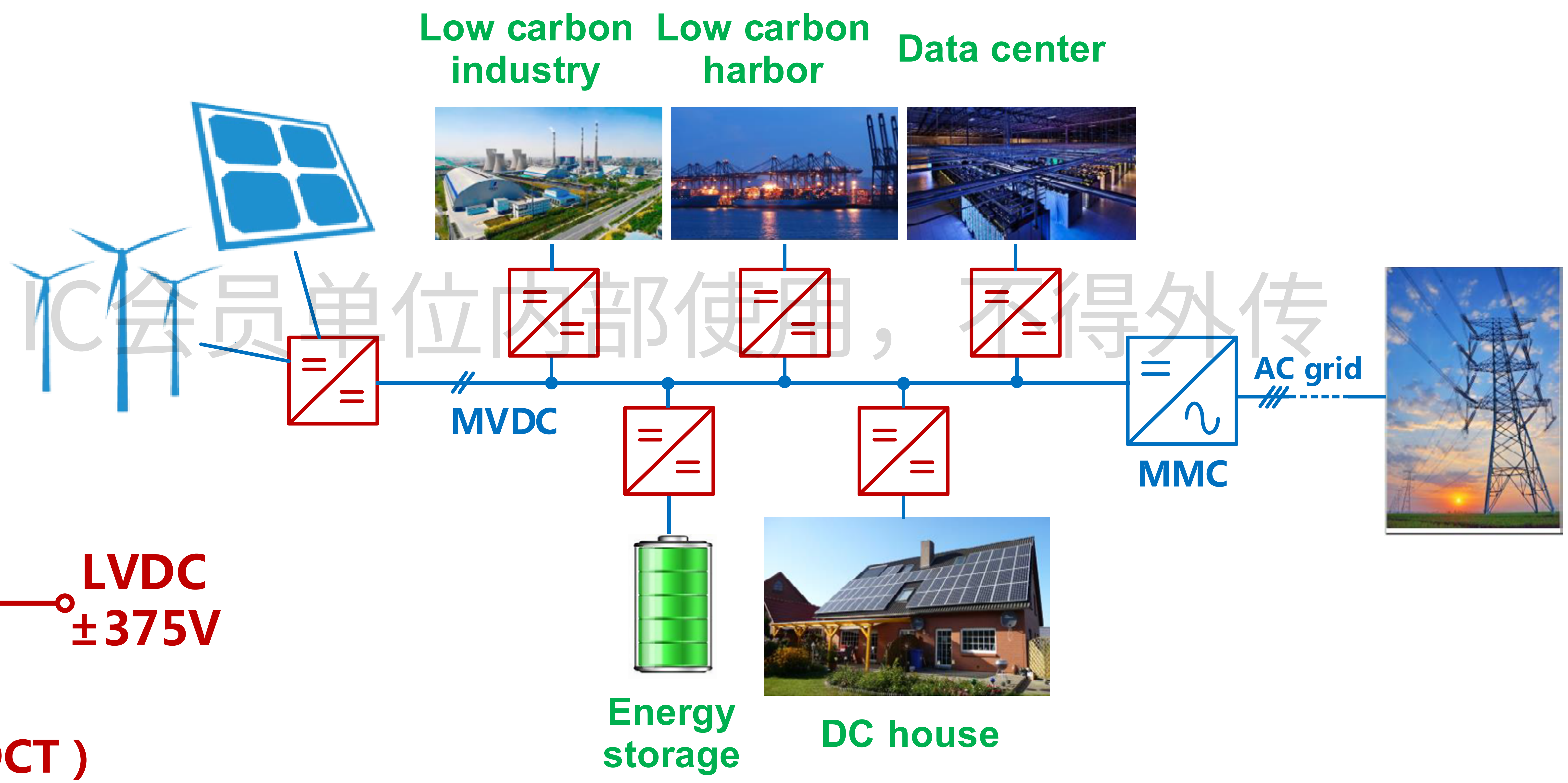
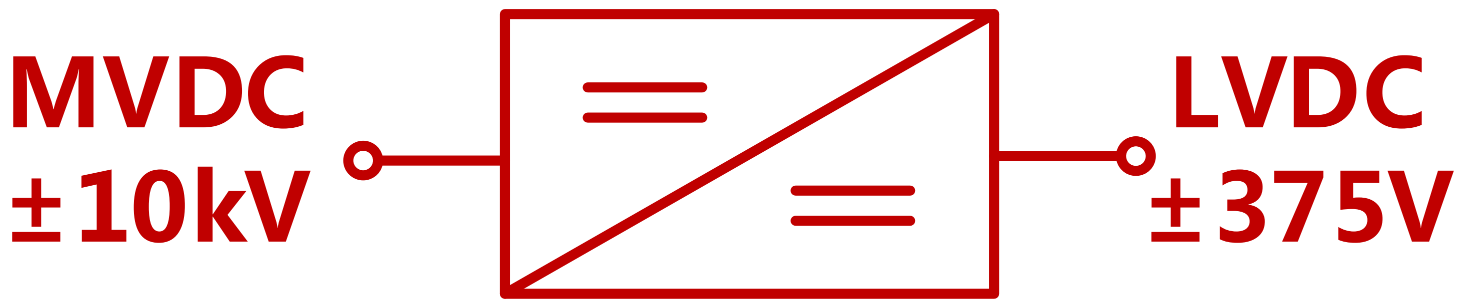
DC Transformer Applications

- **DC Transformer applications：DC grid, Energy storage, Datacenter, DC house…**





DC Transformer（DCT）

[1]李彬彬. 中压配电网中的电力电子变技术探讨. 2021.09.26.

Industrial DCT Demonstrator

中科院电工所1MW
134kW/m³ ±8kV/±375V

国电南瑞2.5MW
~118kW/m³ ±10kV/±375V

中电普瑞 2.5MW
~109kW/m³ ±10kV/±375V

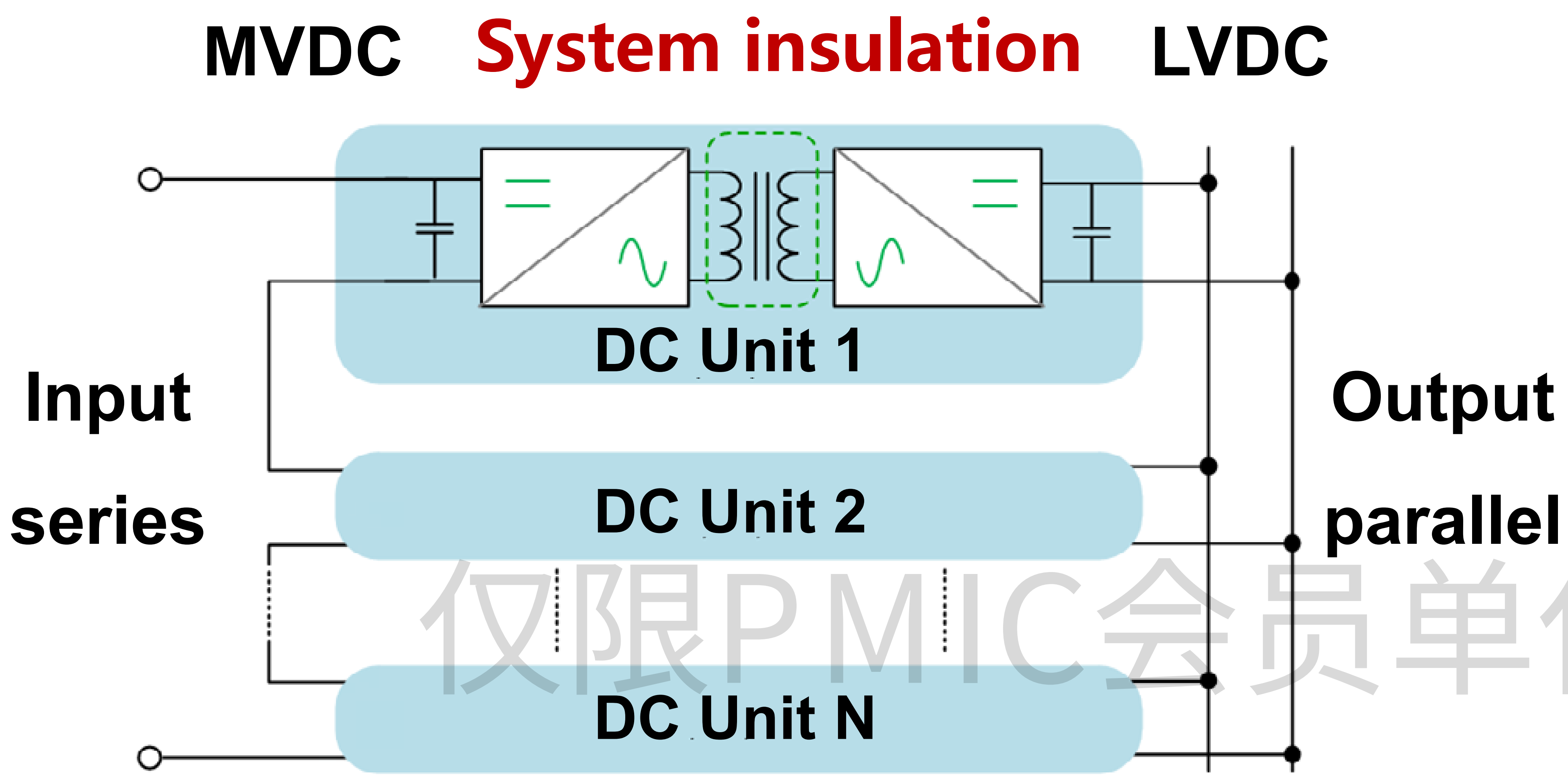
Power Density < 140kW/m³

中国西电2MW
~97kW/m³ ±10kV/±375V

特变电工2MW
~72kW/m³ ±10kV/±375V

许继0.5MW
~71kW/m³ ±10kV/±375V

Power Density Analysis of Conventional DCT



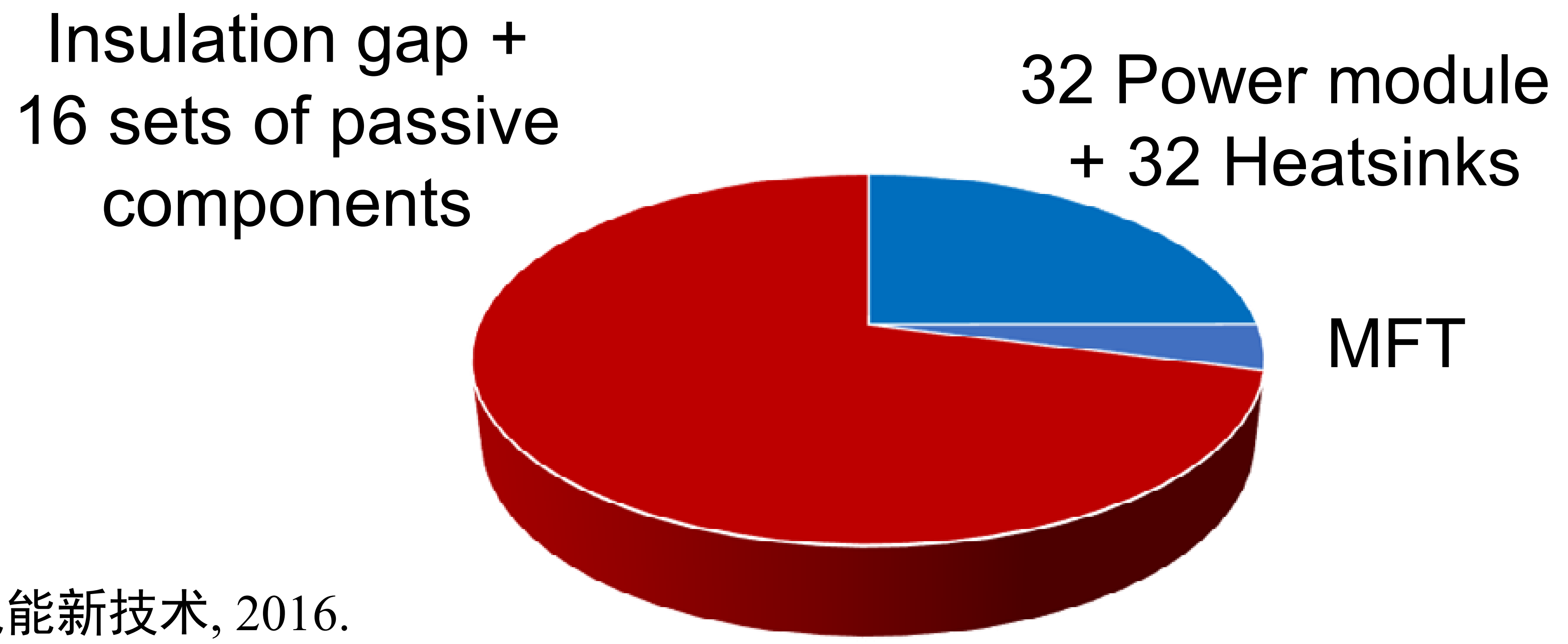
- Volume analysis (中科院电工所1MW样机)

±8kV/±375V 1MW
16 DC units

Component	Size/m^3
32 Power module + 32 Heatsinks	**1.861**
Insulation gap + 16 sets of passive components	**5.3**
MFT	**0.291**

- Reasons of low power density :

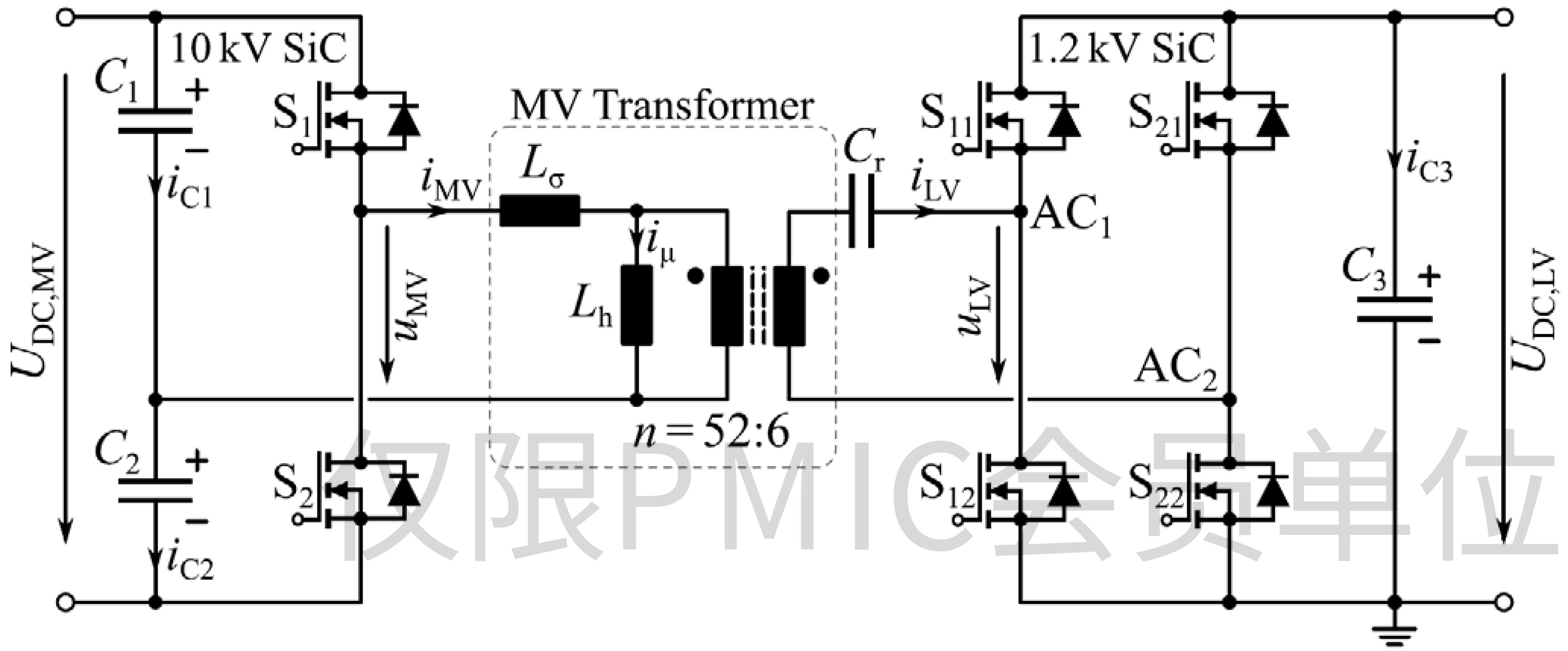
> - **Large insulation gap**
> - **Large number of passive components**

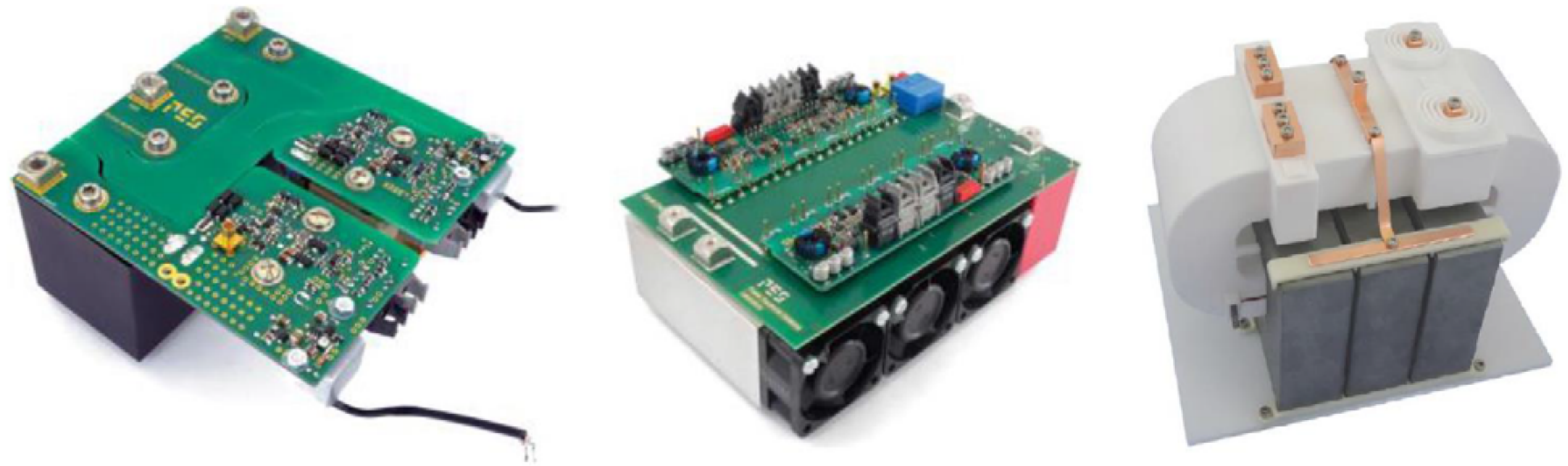


[1]李子欣等. 中压配电网用10kVac-750Vdc/1MVA电力电子变压器功率密度影响因素研究[J]. 电工电能新技术, 2016.

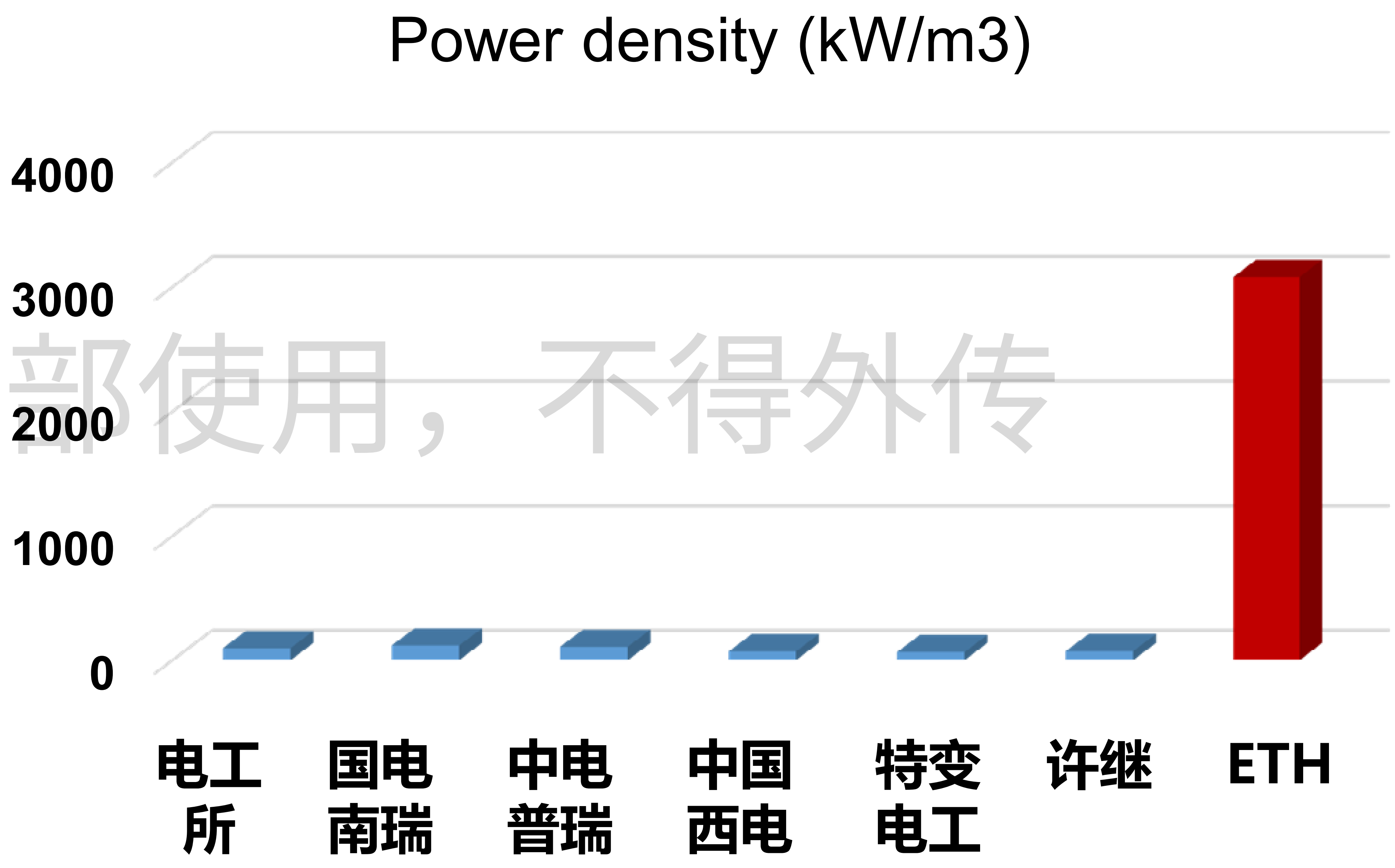
DCT with Single Transformer

- **DCT with single transformer can achieve much higher density**





ETH zürich



[1] D. Rothmund, T. Guillod, D. Bortis and J. W. Kolar, "99% Efficient 10 kV SiC-Based 7 kV/400 V DC Transformer for Future Data Centers," in *IEEE Journal of Emerging and Selected Topics in Power Electronics*
[2] 李子欣, 高范强, 徐飞,等. 中压配电网用10kVac-750Vdc/1MVA电力电子变压器功率密度影响因素研究[J]. 电工电能新技术, 2016, 35(006):1-6.

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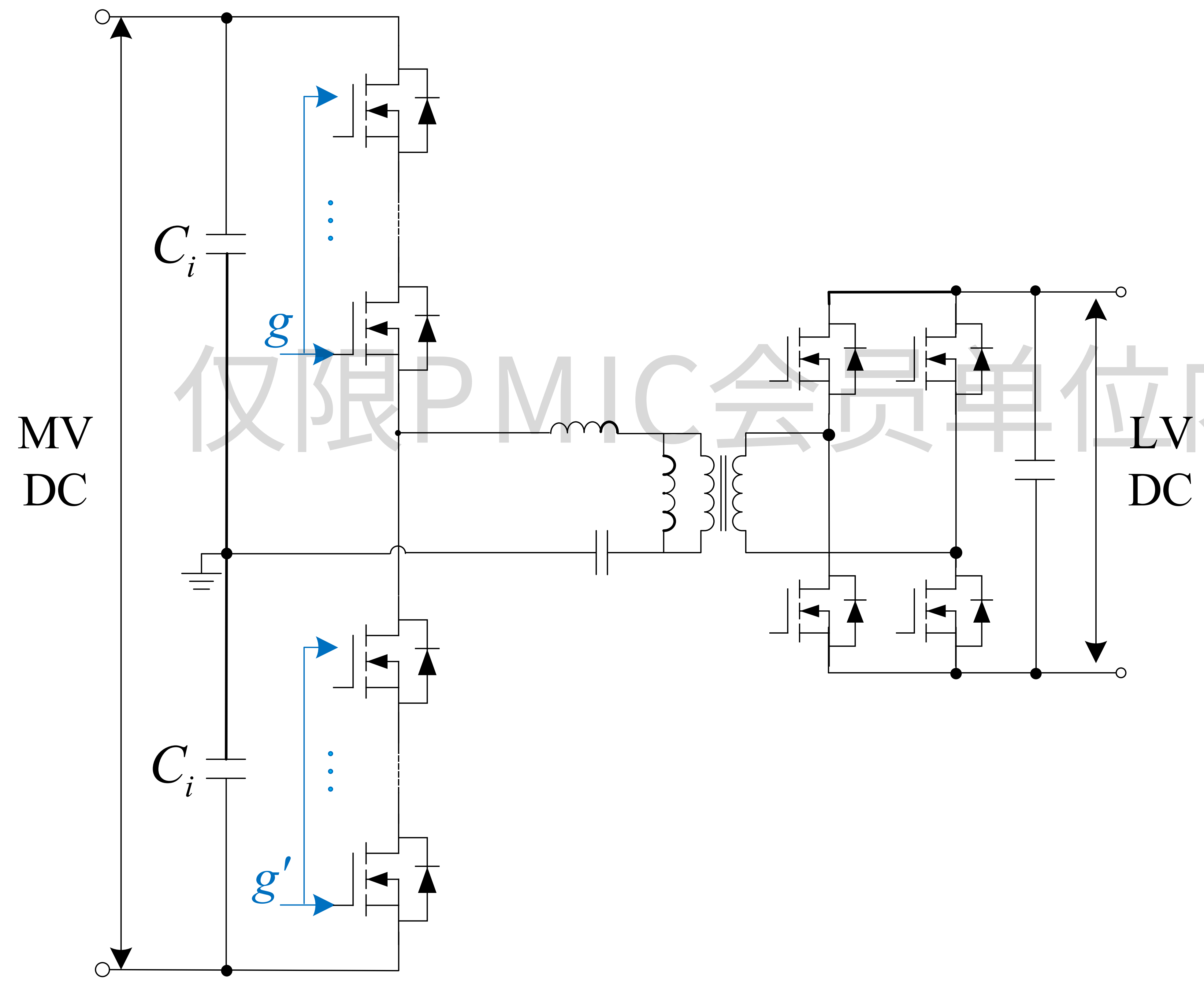
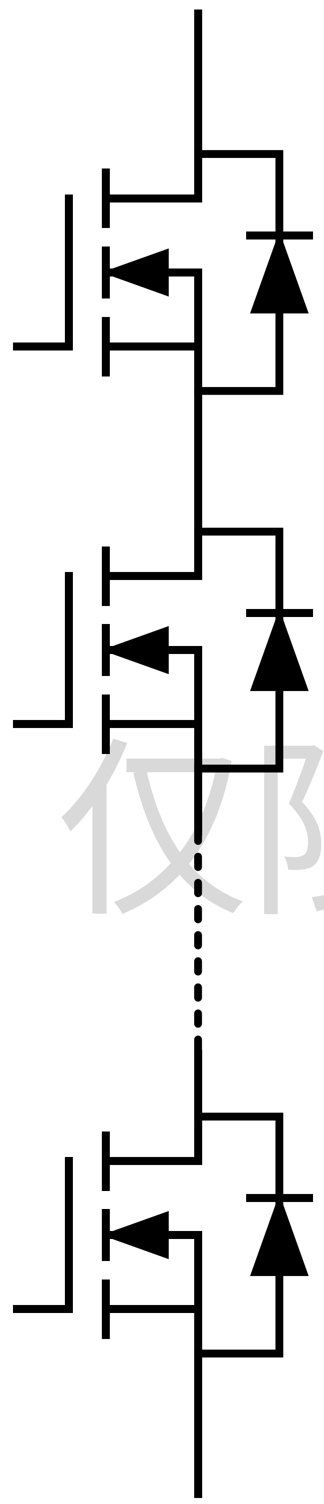
DCT with series-connected power devices



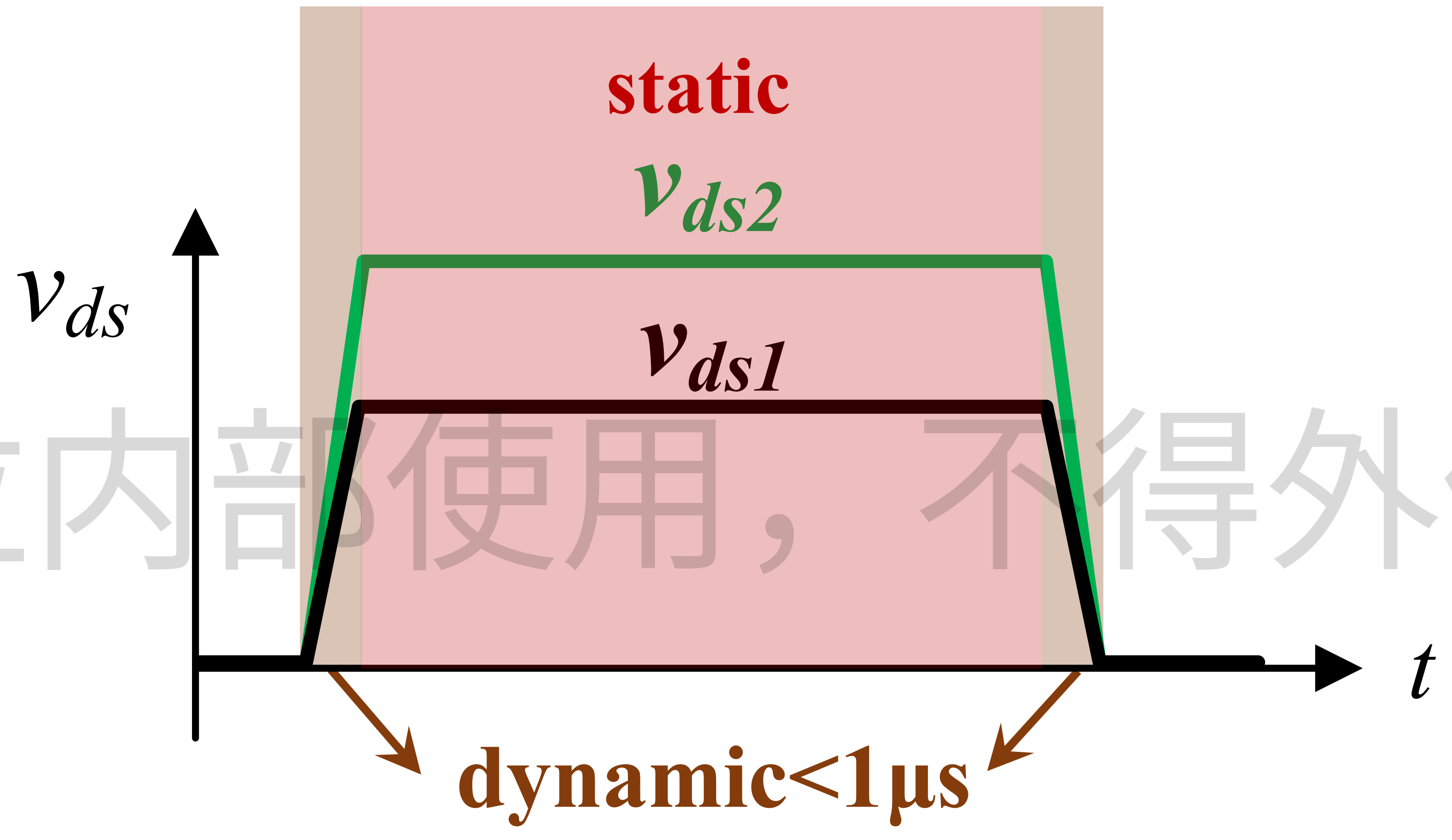
- ✓ DCT can achieve high power density
- ✓ Mature 1.2~1.7kV SiC MOSFETs are available

Challenges of Series–Connected Devices



Over-voltage → **Damage**

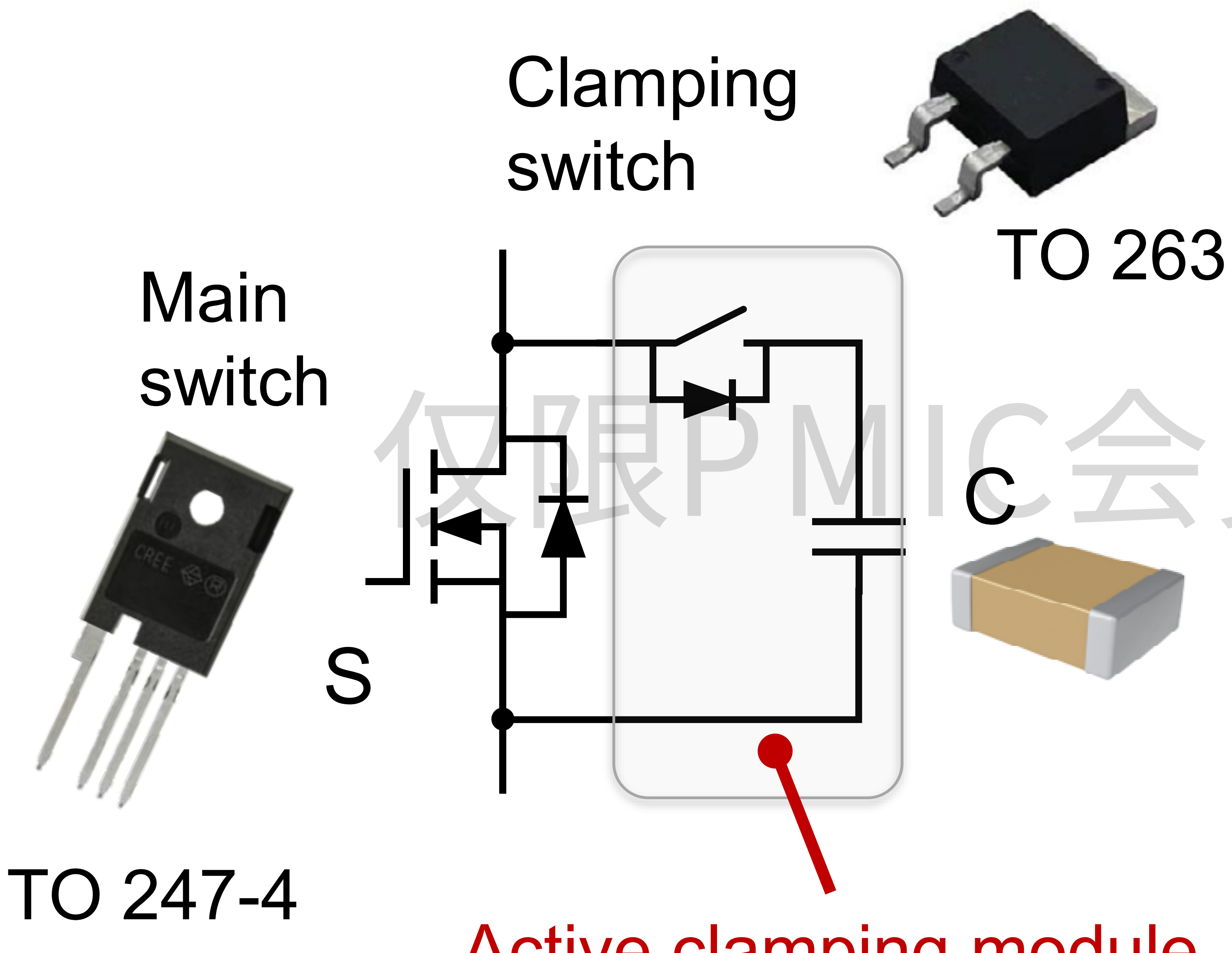
Key Challenge: voltage sharing

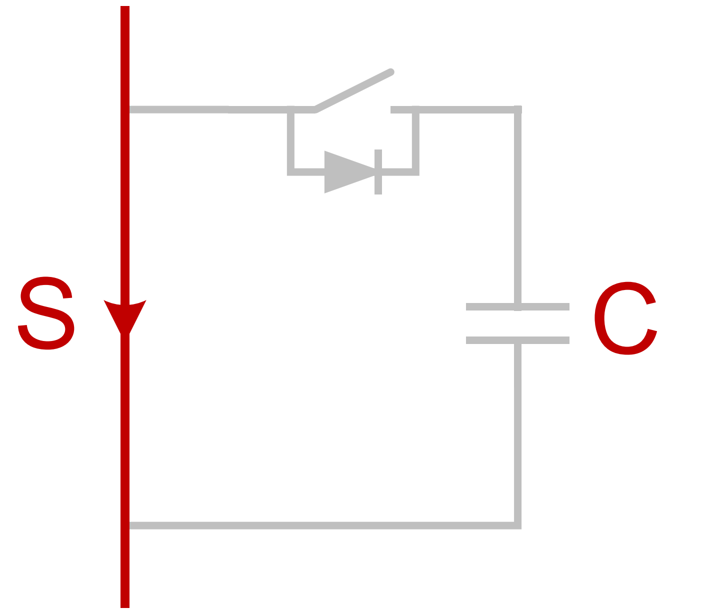


☐ Reasons of voltage imbalance

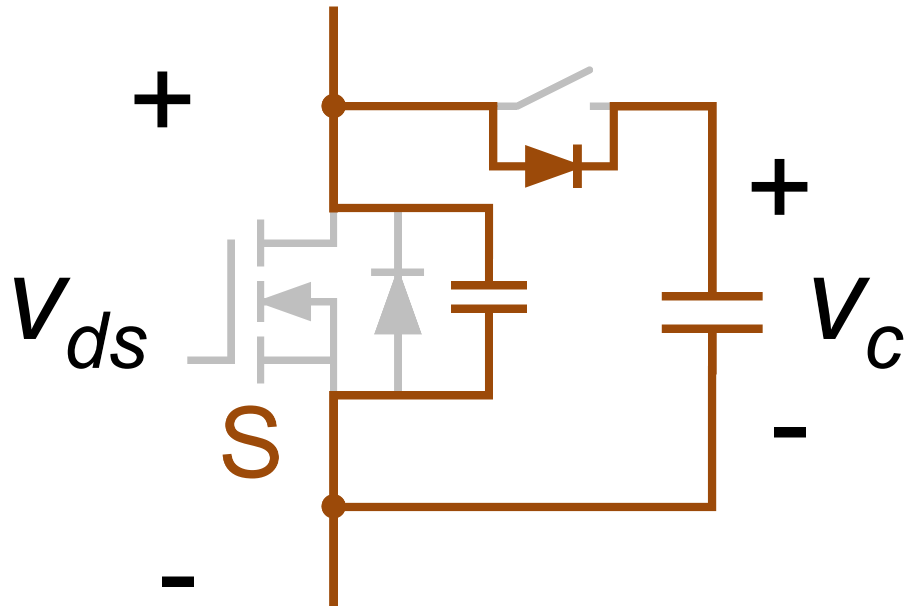
- **Devices internal parameter:** threshold voltage, parasite capacitor, leakage current, etc.
- **External circuit parameter**: trigger delay, trigger resistor, parasite parameter, temperature, etc.

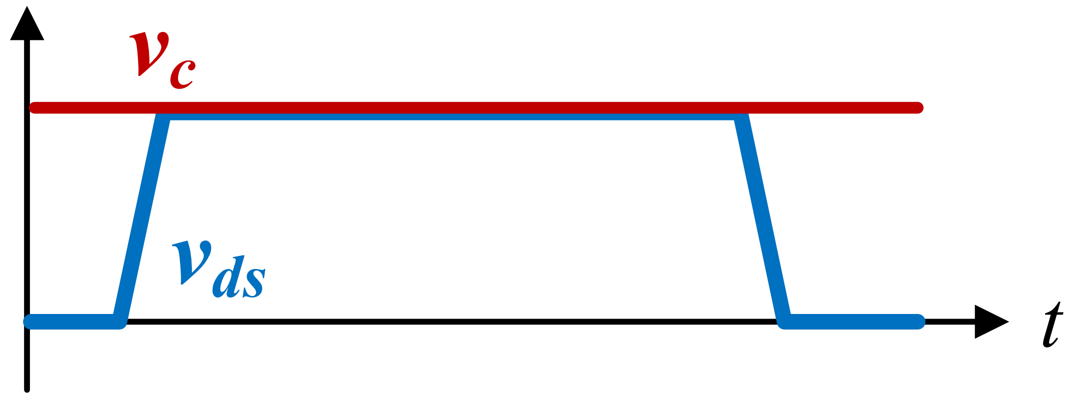
Active clamping module





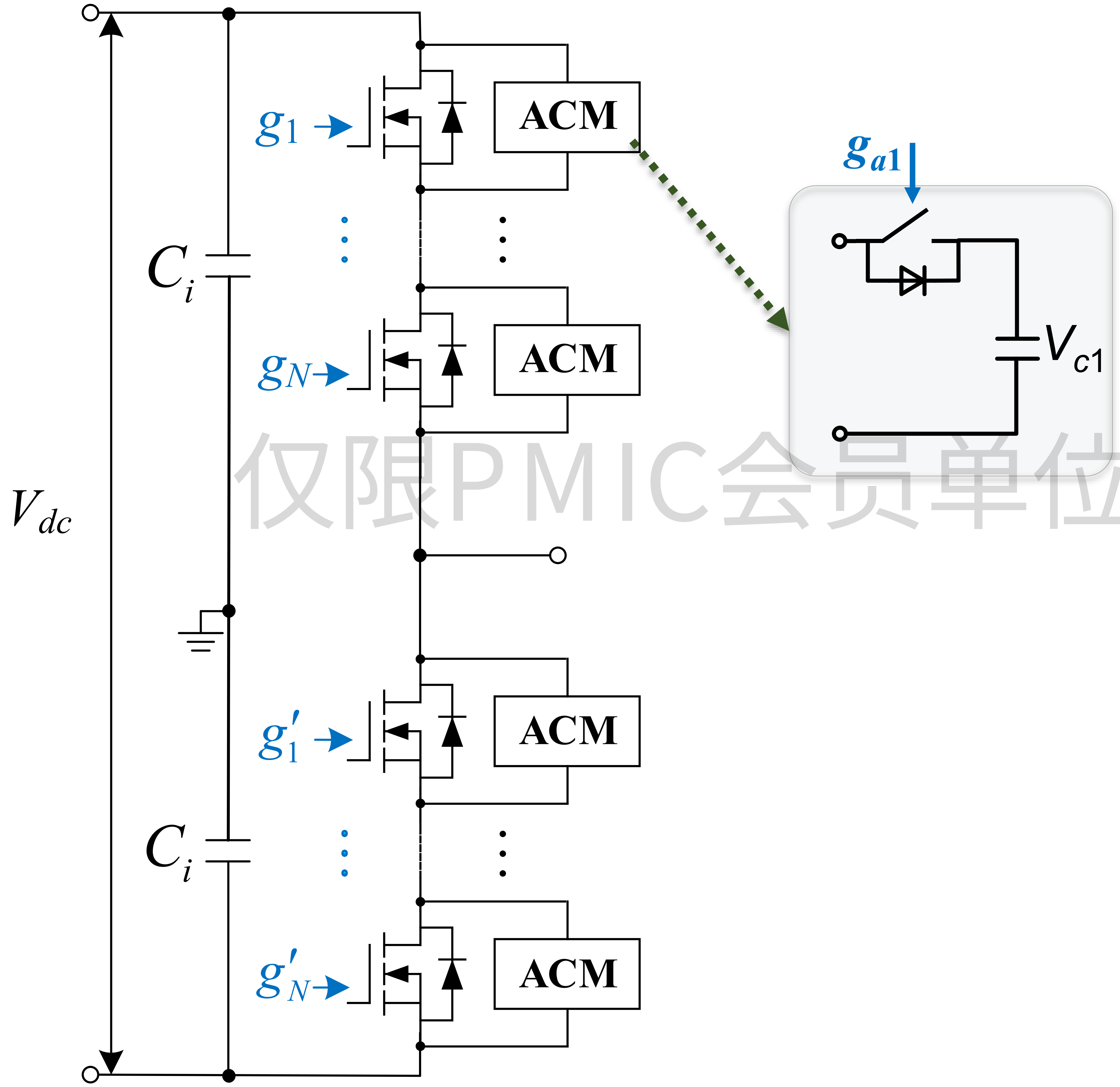
S conducts, C is bypassed.





S turns off，v_{ds} is clamped to v_c

Series connection of power devices



When ACM capacitor voltages:

$V_{c1} = V_{c2} = \ldots = V_{cN} = V_{dc}/N$

The **N** series-connected power devices are well balanced.

DCT based on series connection of power devices

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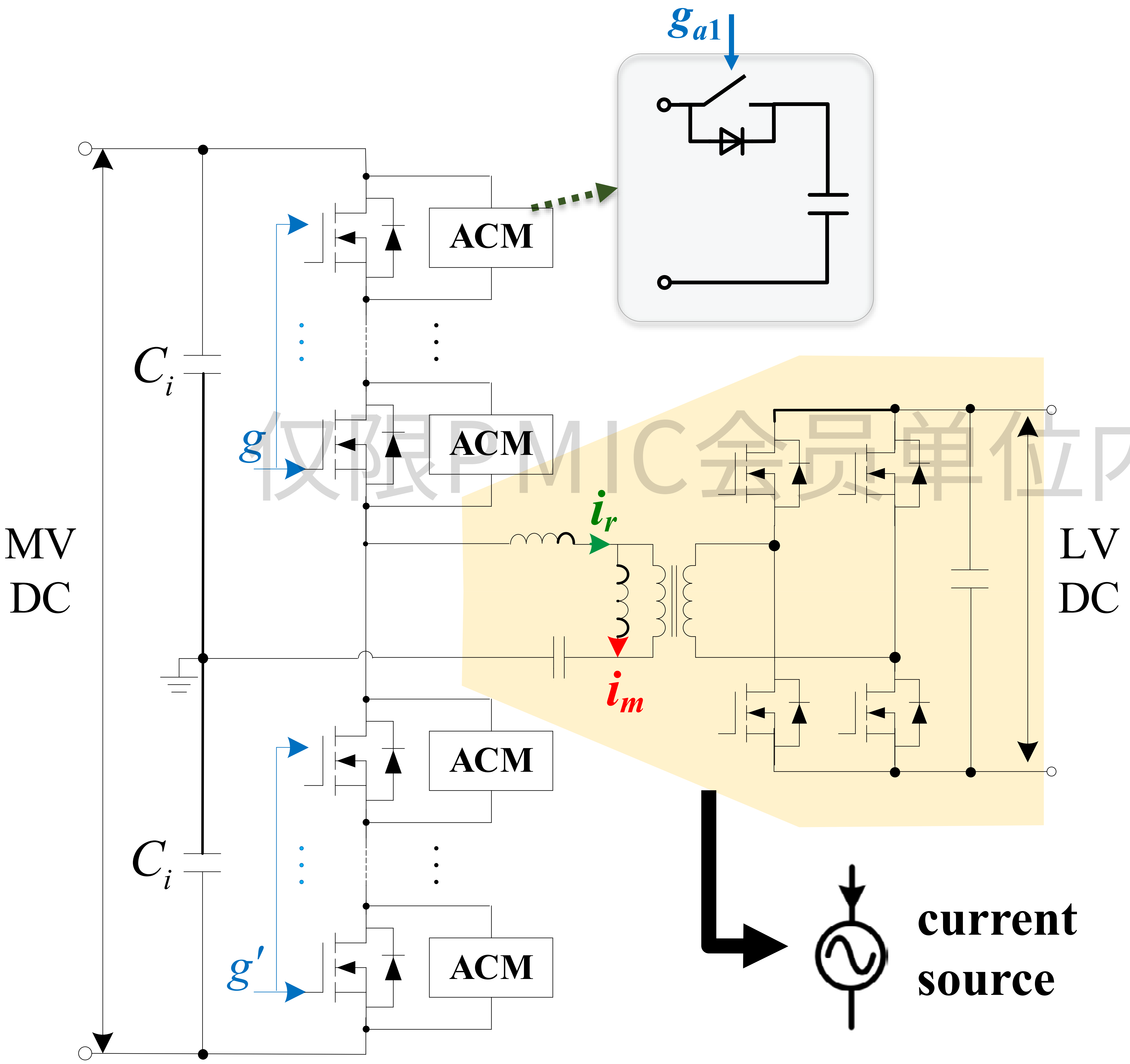
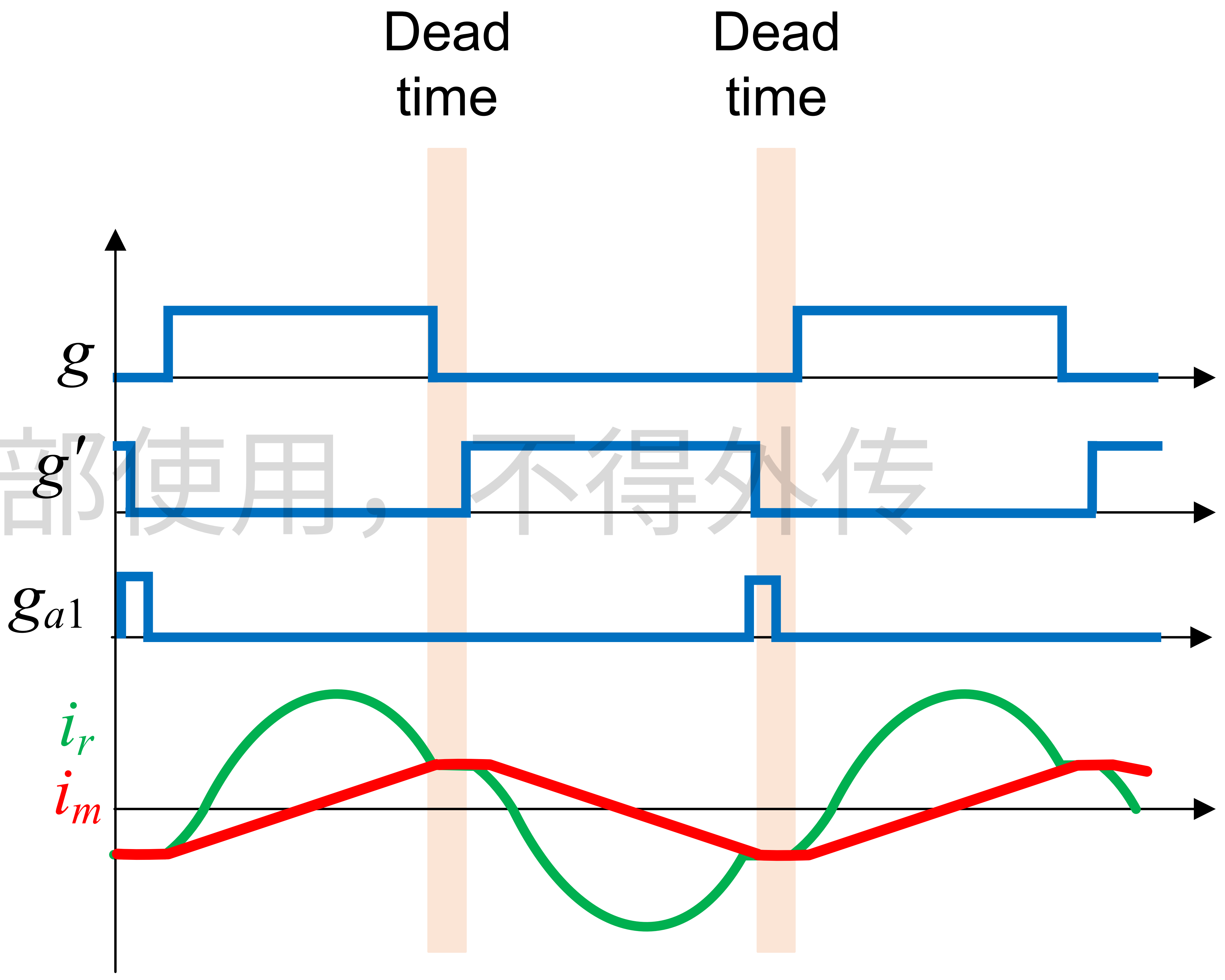
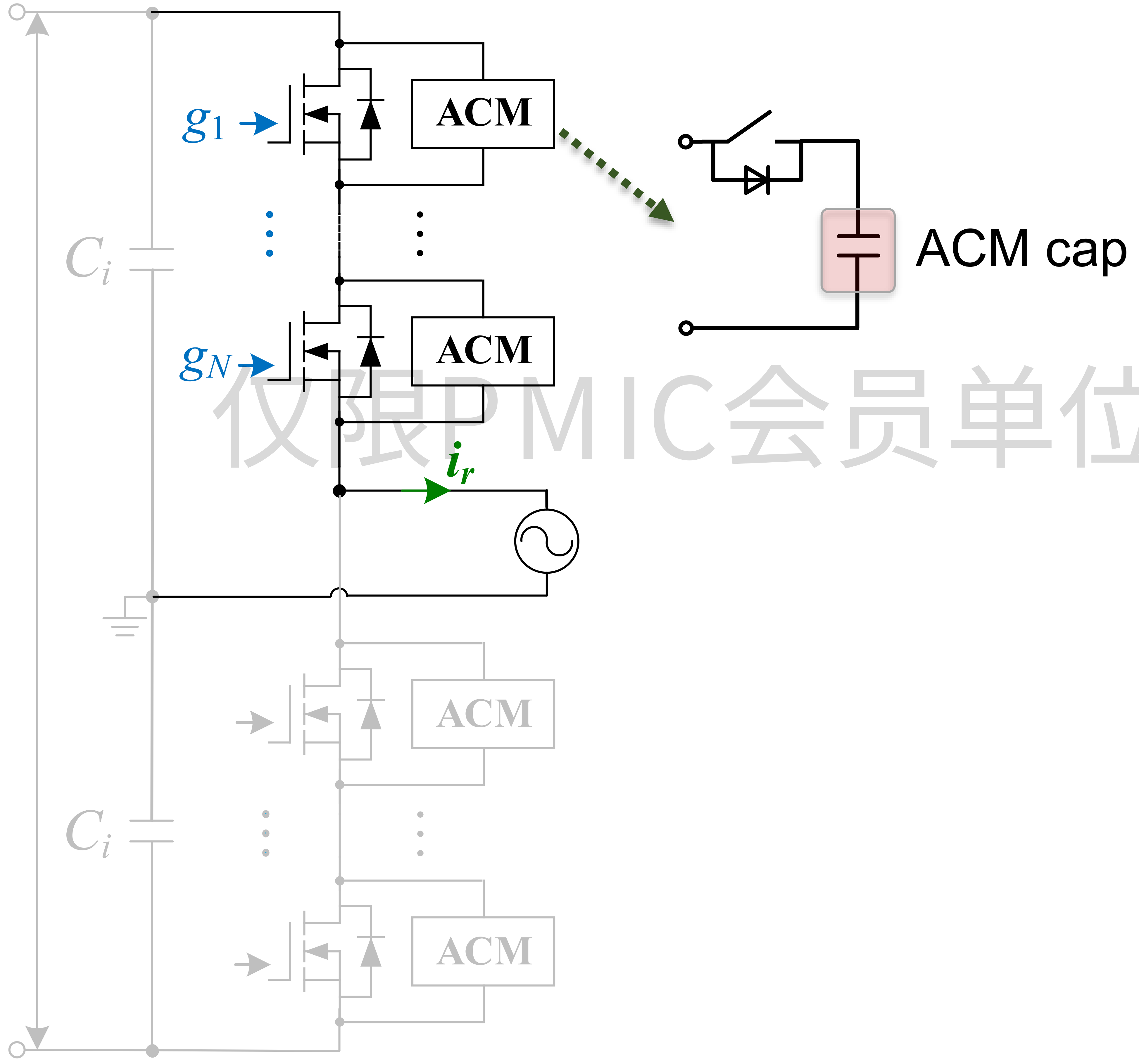
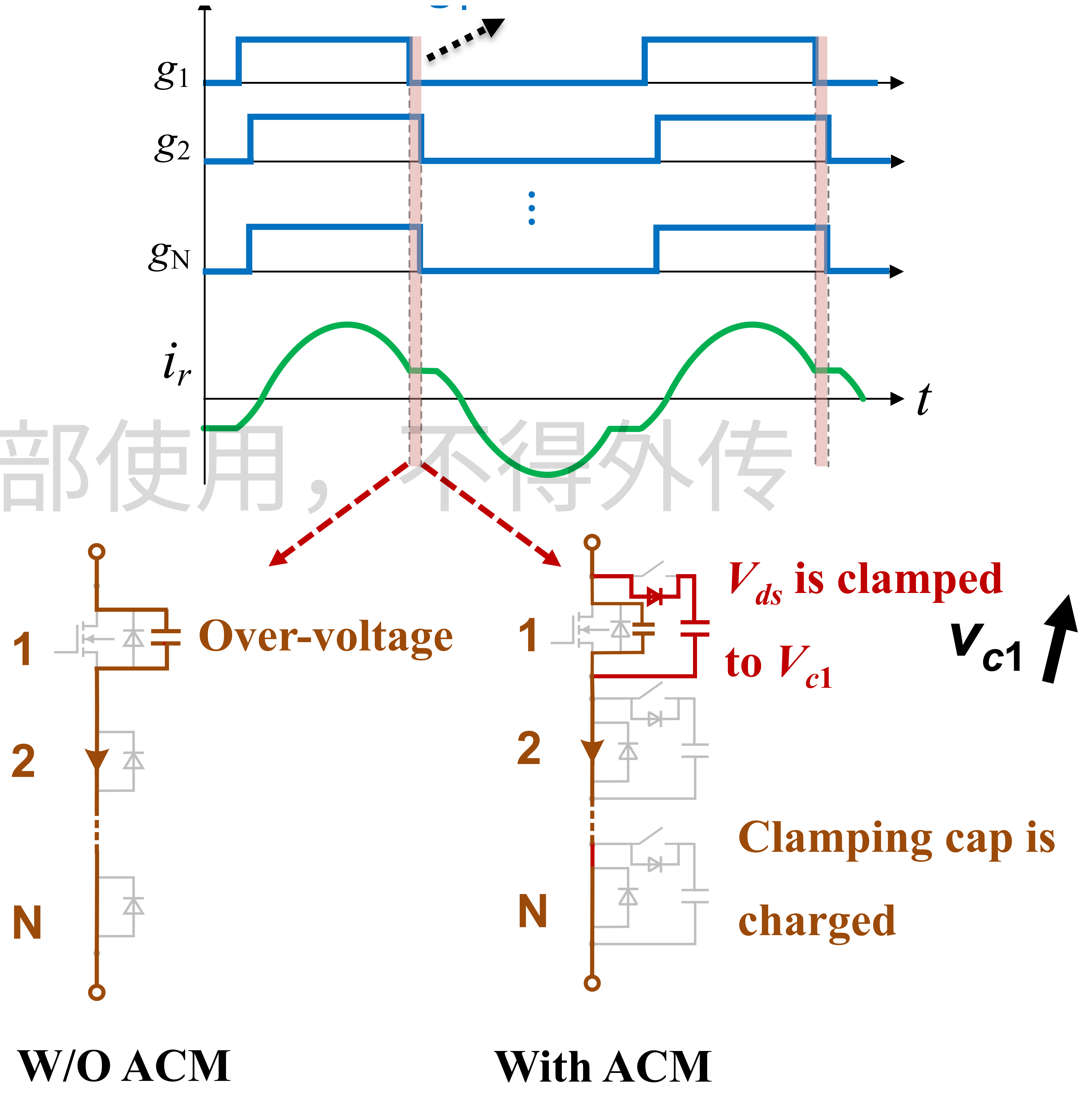




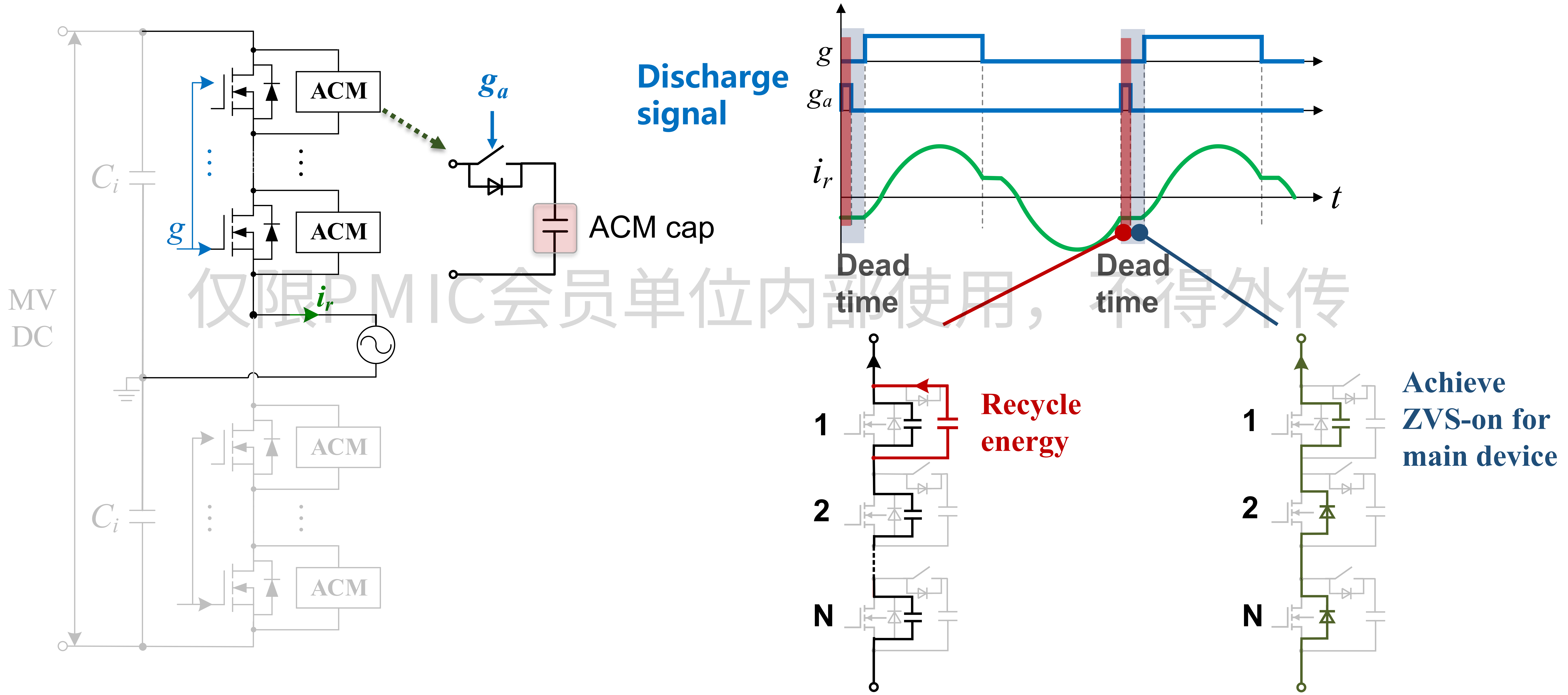
Charging of ACM capacitor

- Any asynchronization will charge the ACM cap.

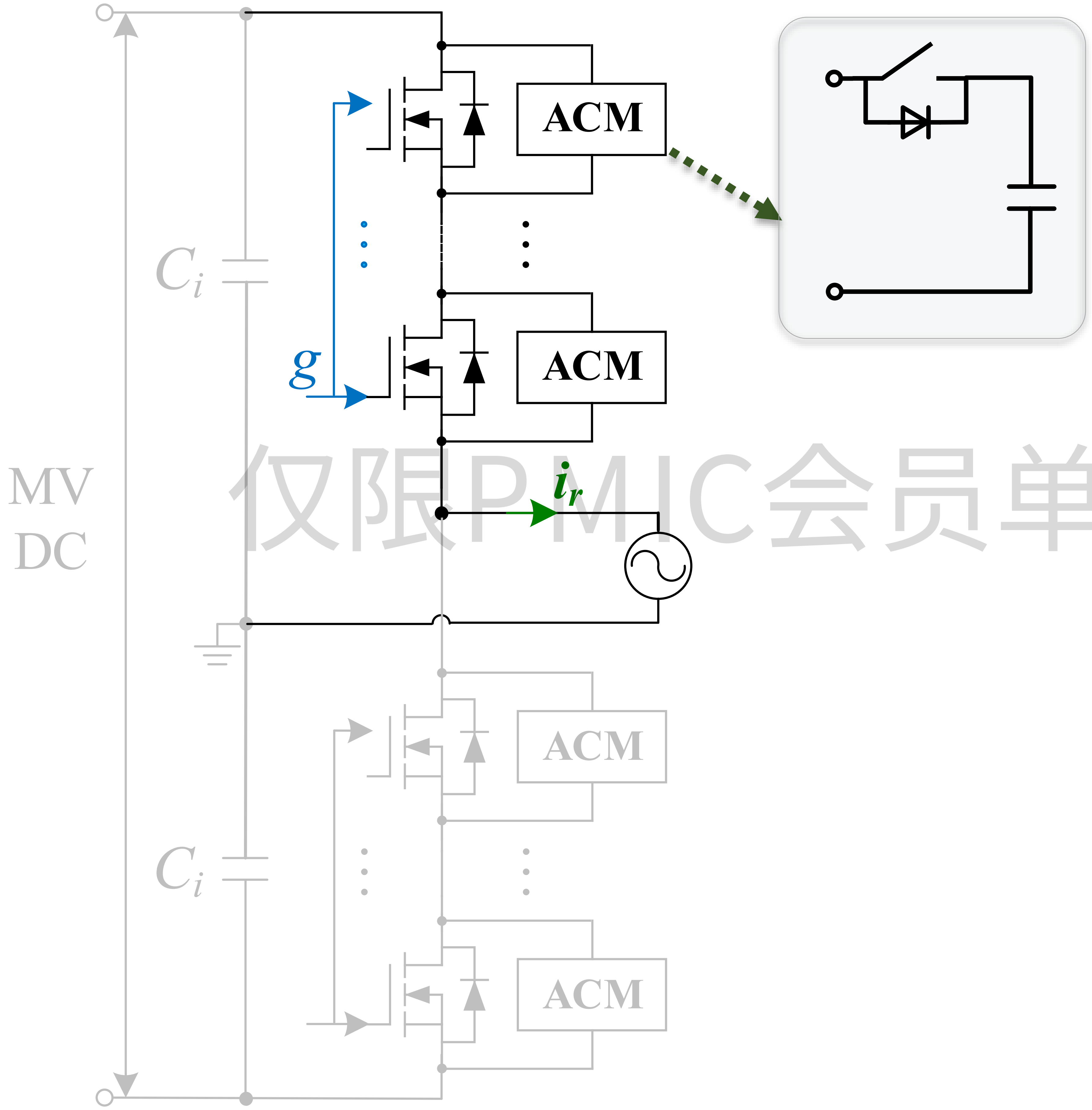


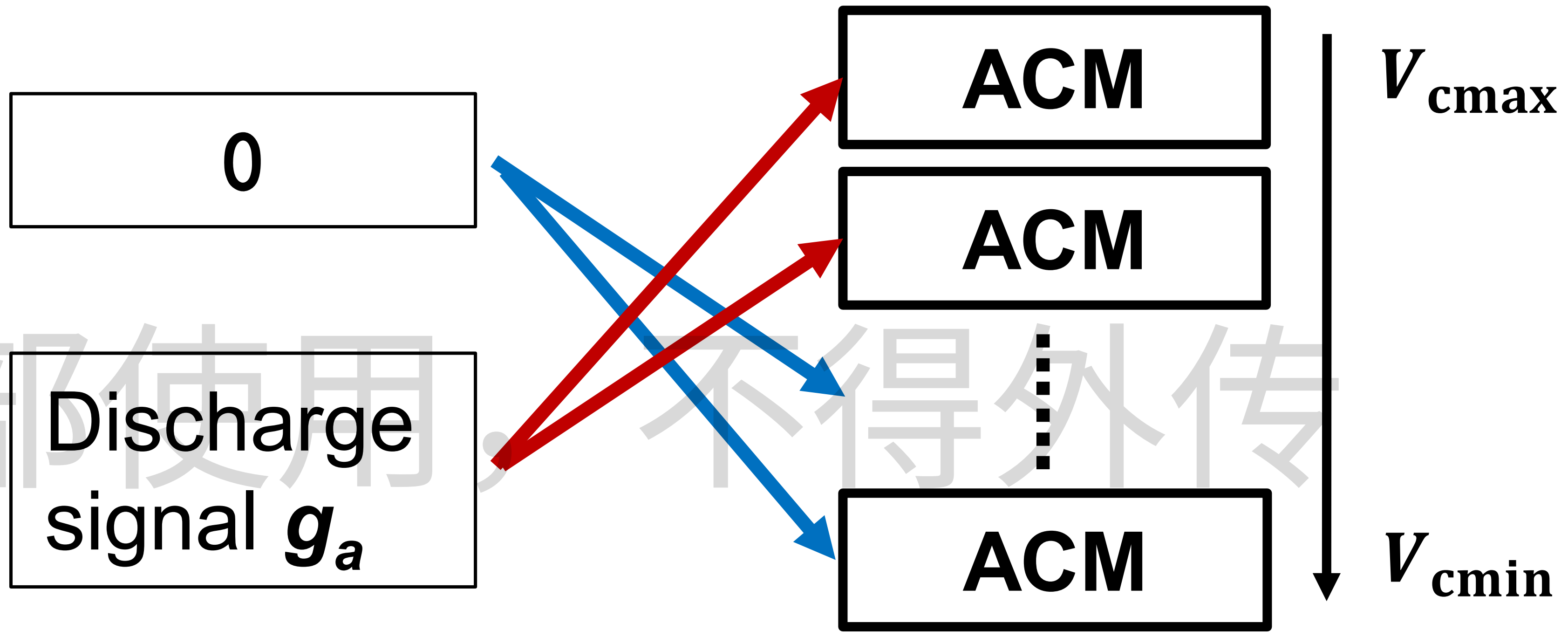


Discharge of ACM cap



Balancing control strategy

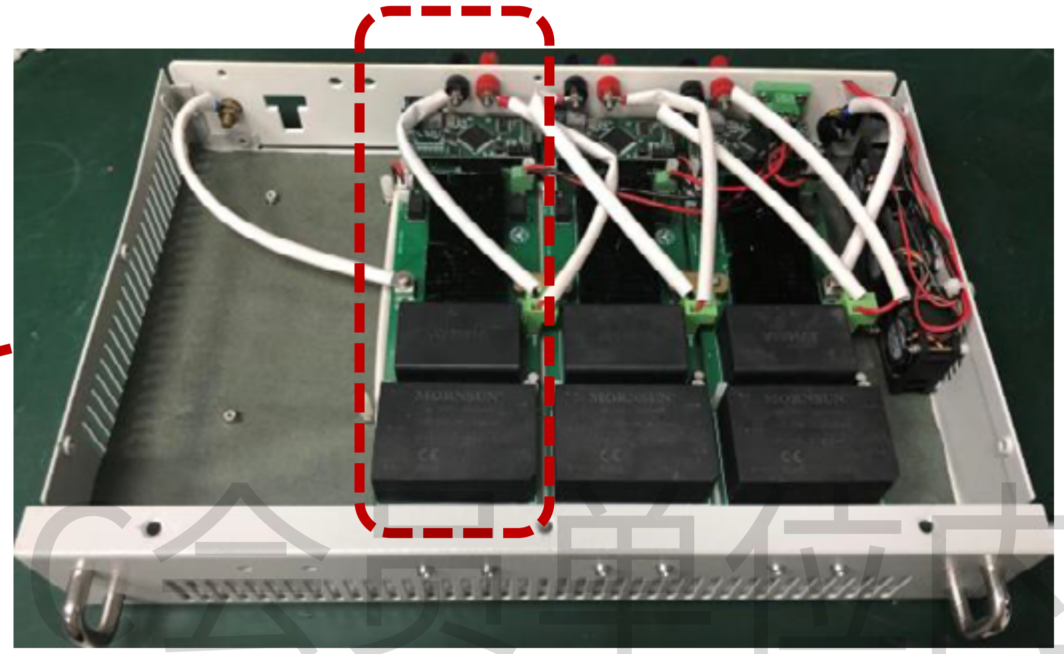




Select ***k*** ACMs with higher voltages to discharge.

Prototype with 6 series–connected SiC MOSFET

Power device
and its ACM

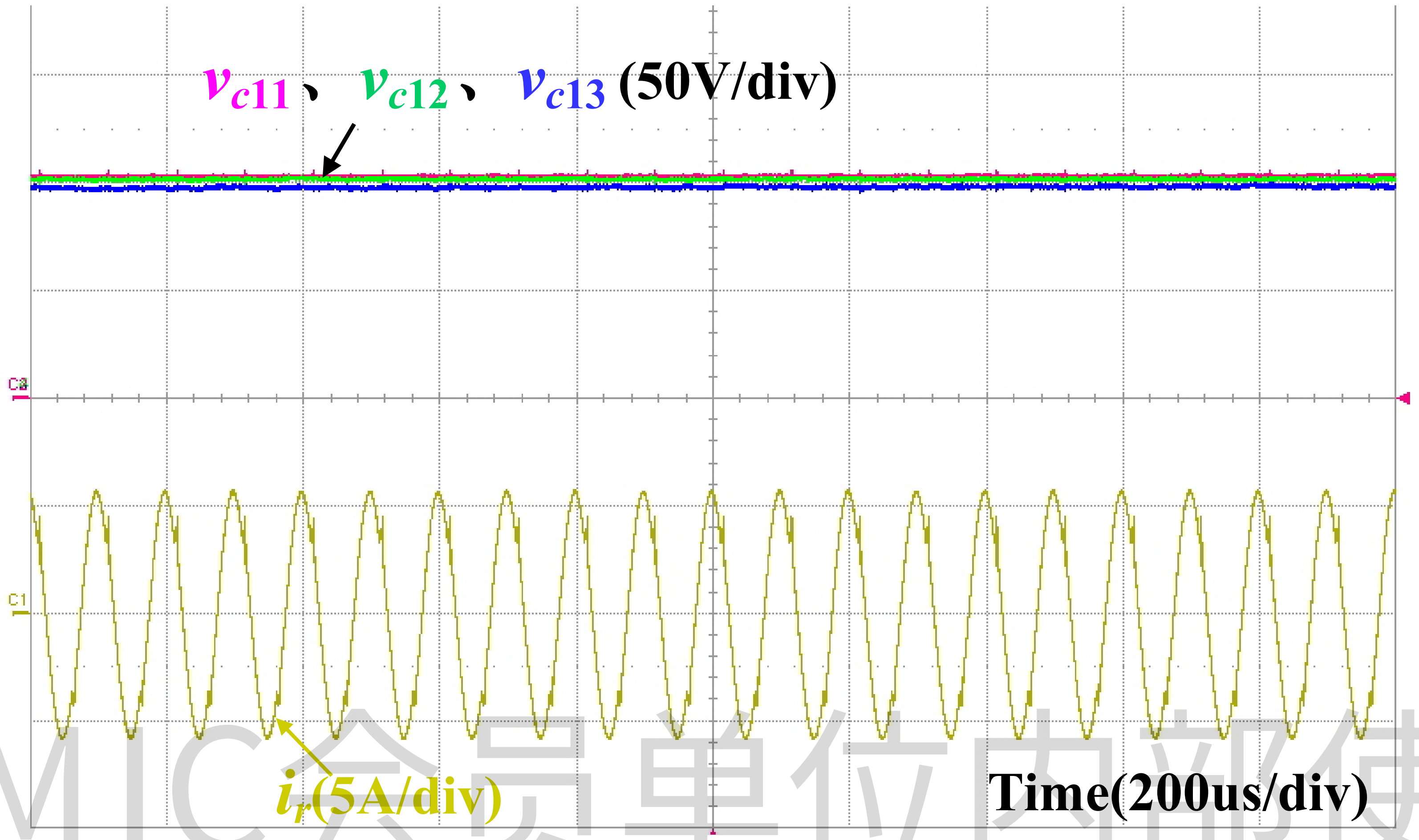


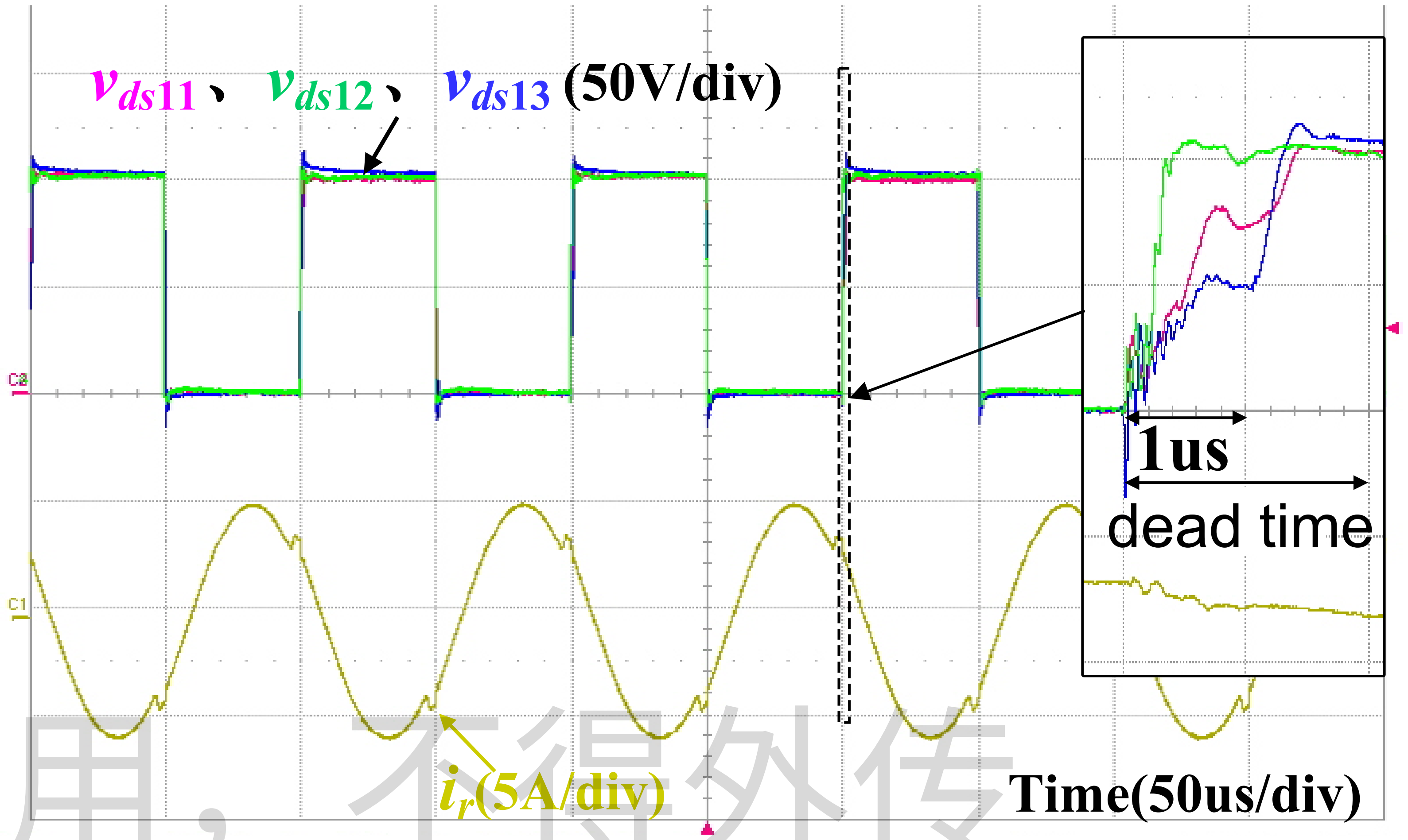
■ **Prototype parameters**

Parameters	Value
Input voltage	3kV
Output voltage	750V
Output power	30kW
No. of series-connected devices	6
Switching frequency	10kHz
Dead time	2μs
Discharge time	1μs
Clamping cap	20μF

Experimental results

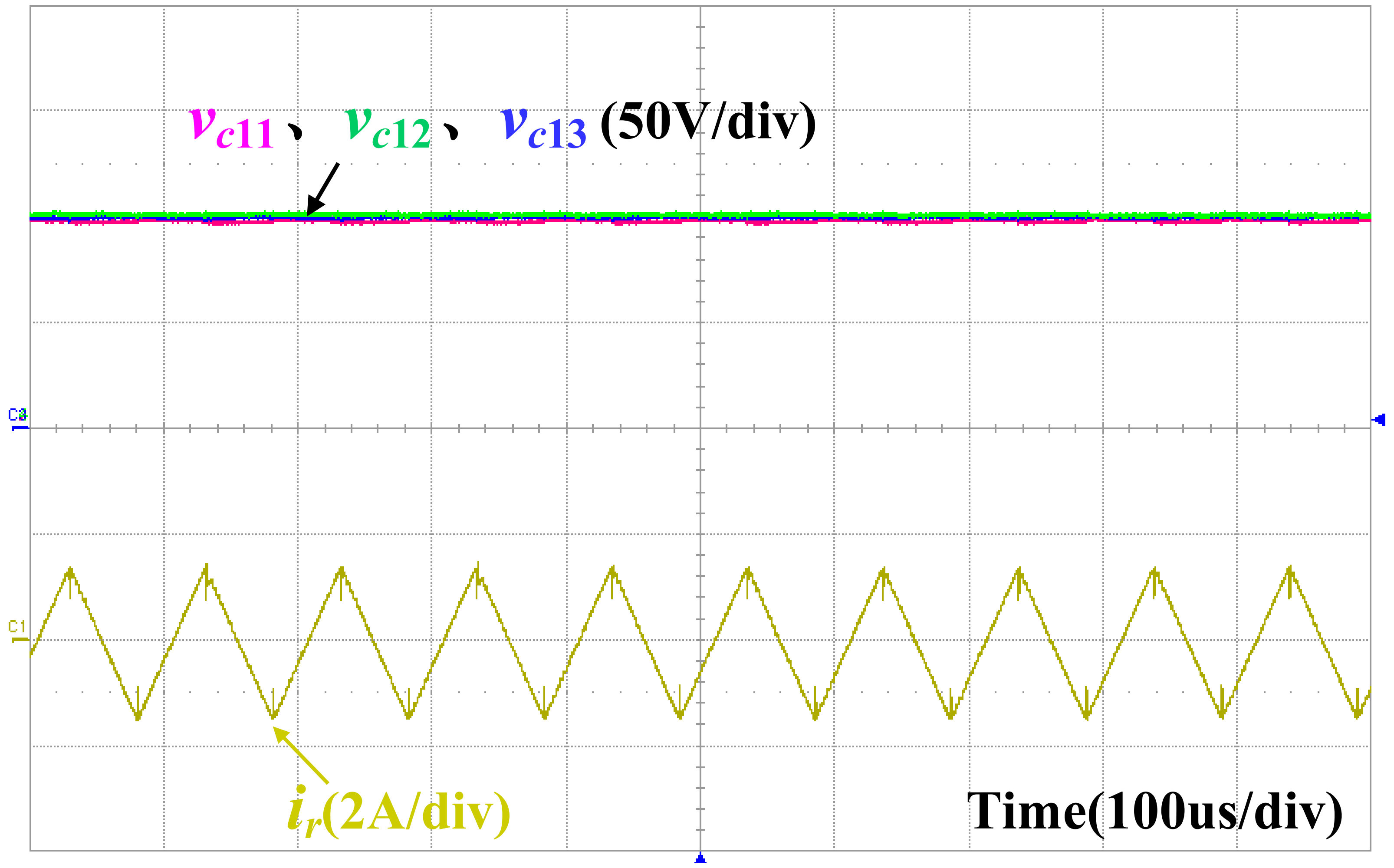
V_i=600V，P=1kW

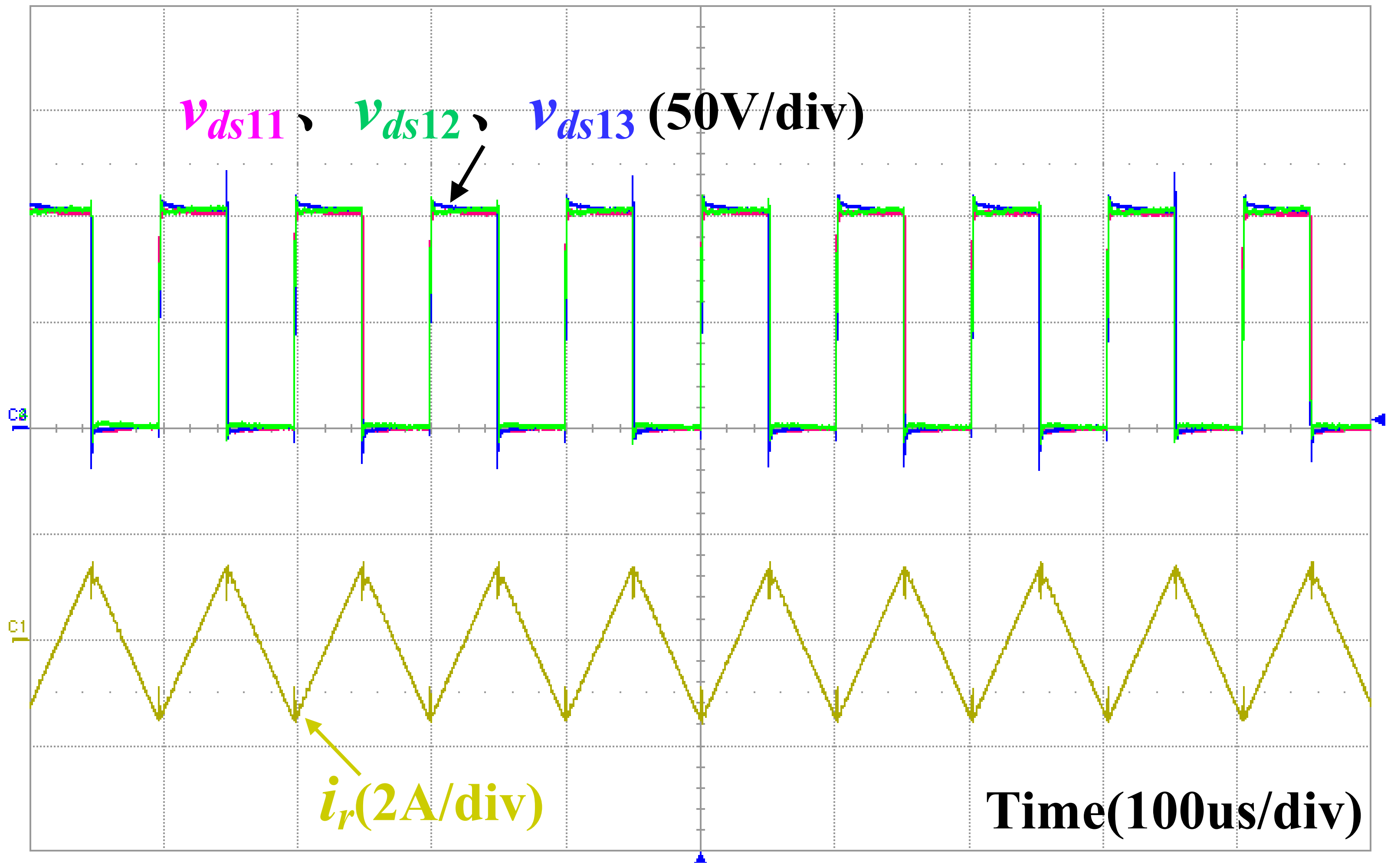




Imbalance degree of series devices **< 5%**

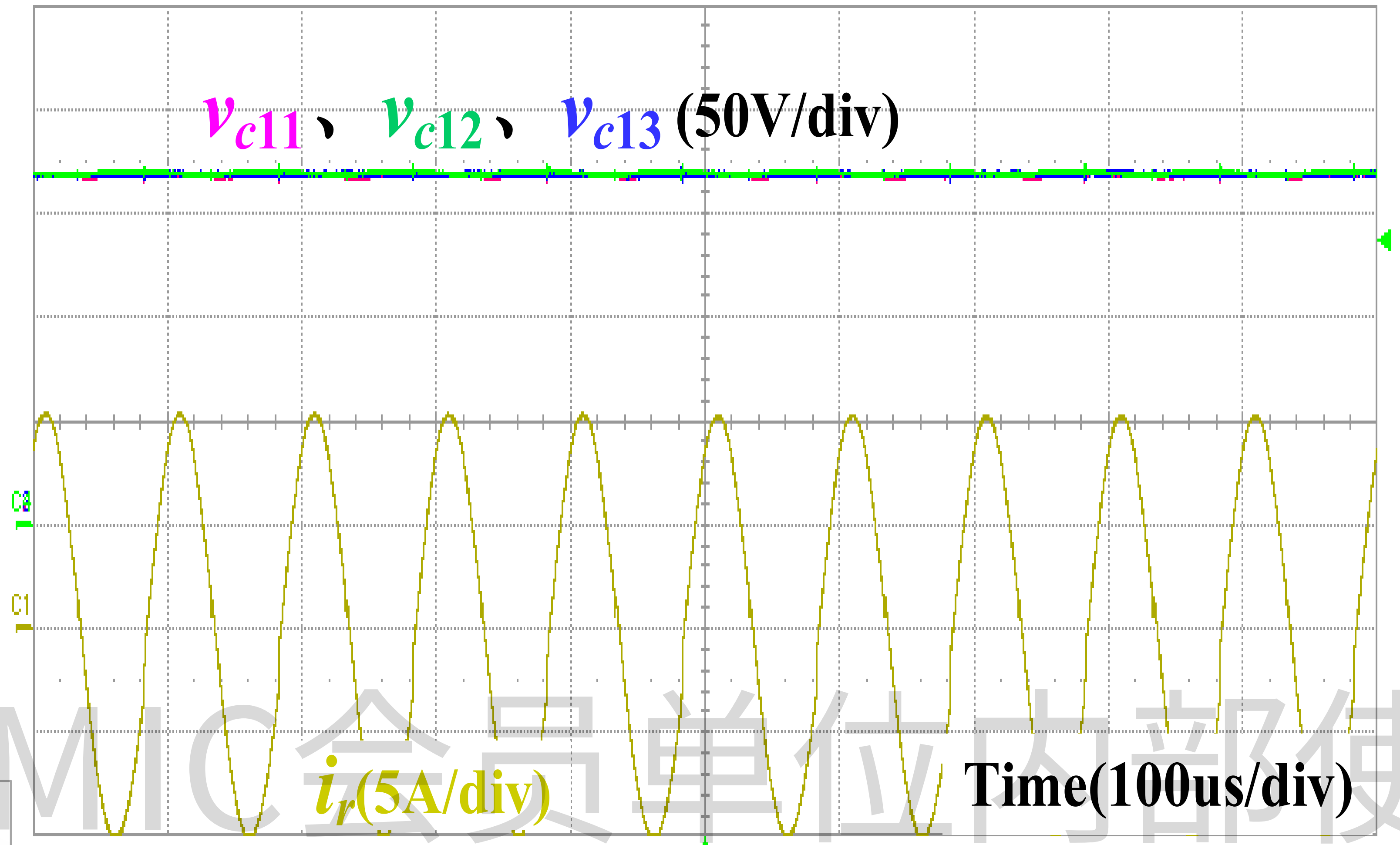
V_i=600V，No load

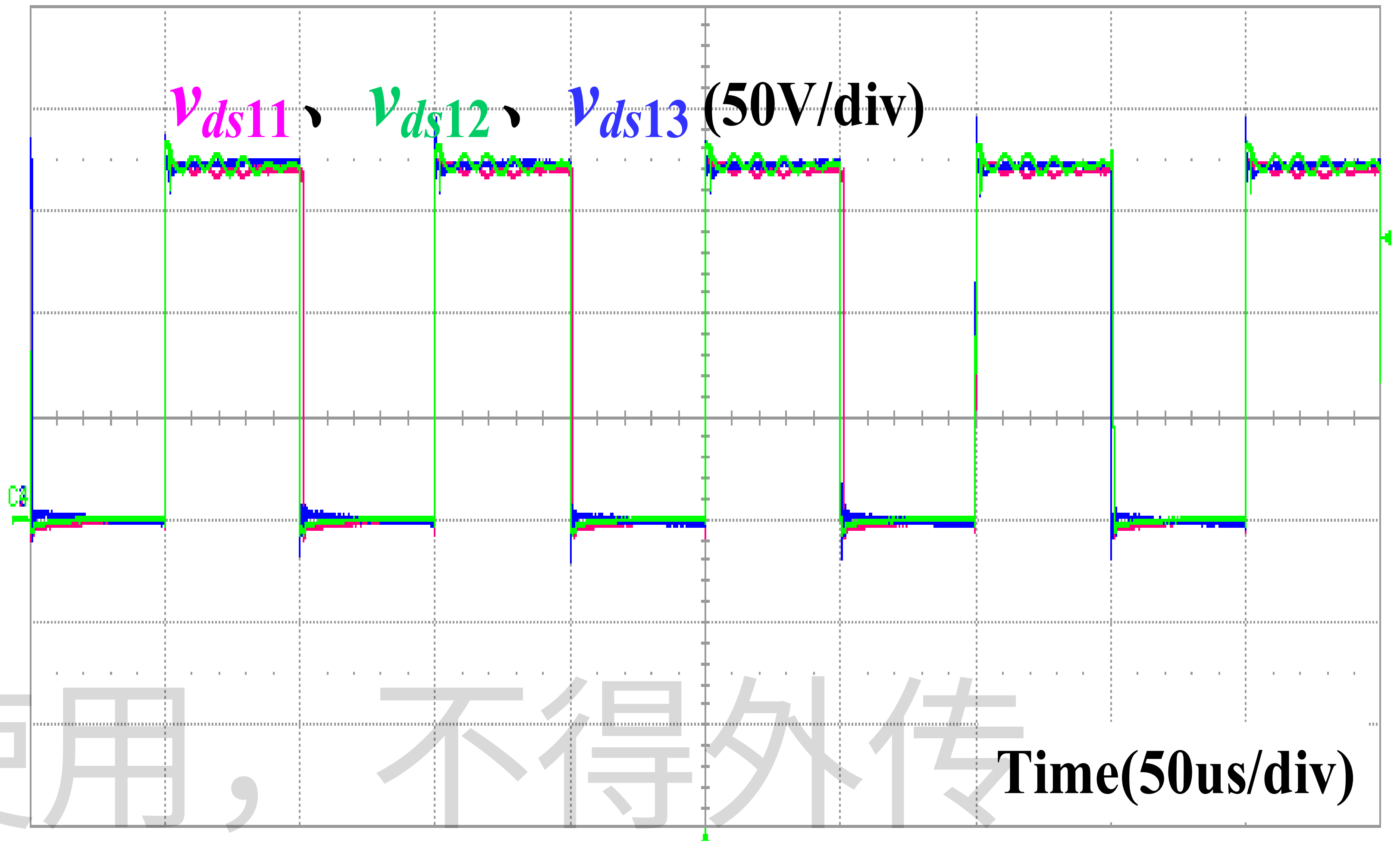




Experimental results

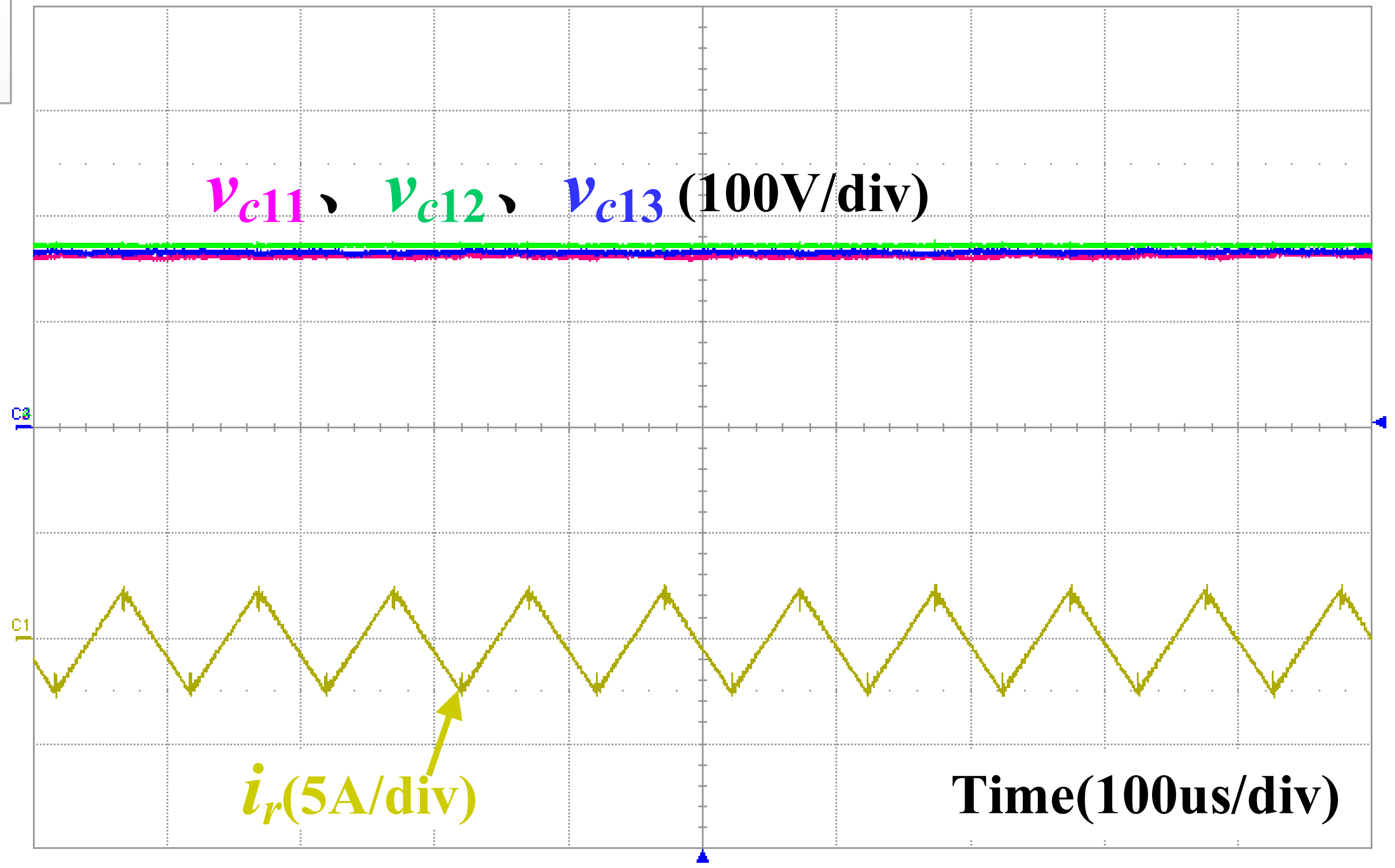
V_i=1kV， P=3.3kW

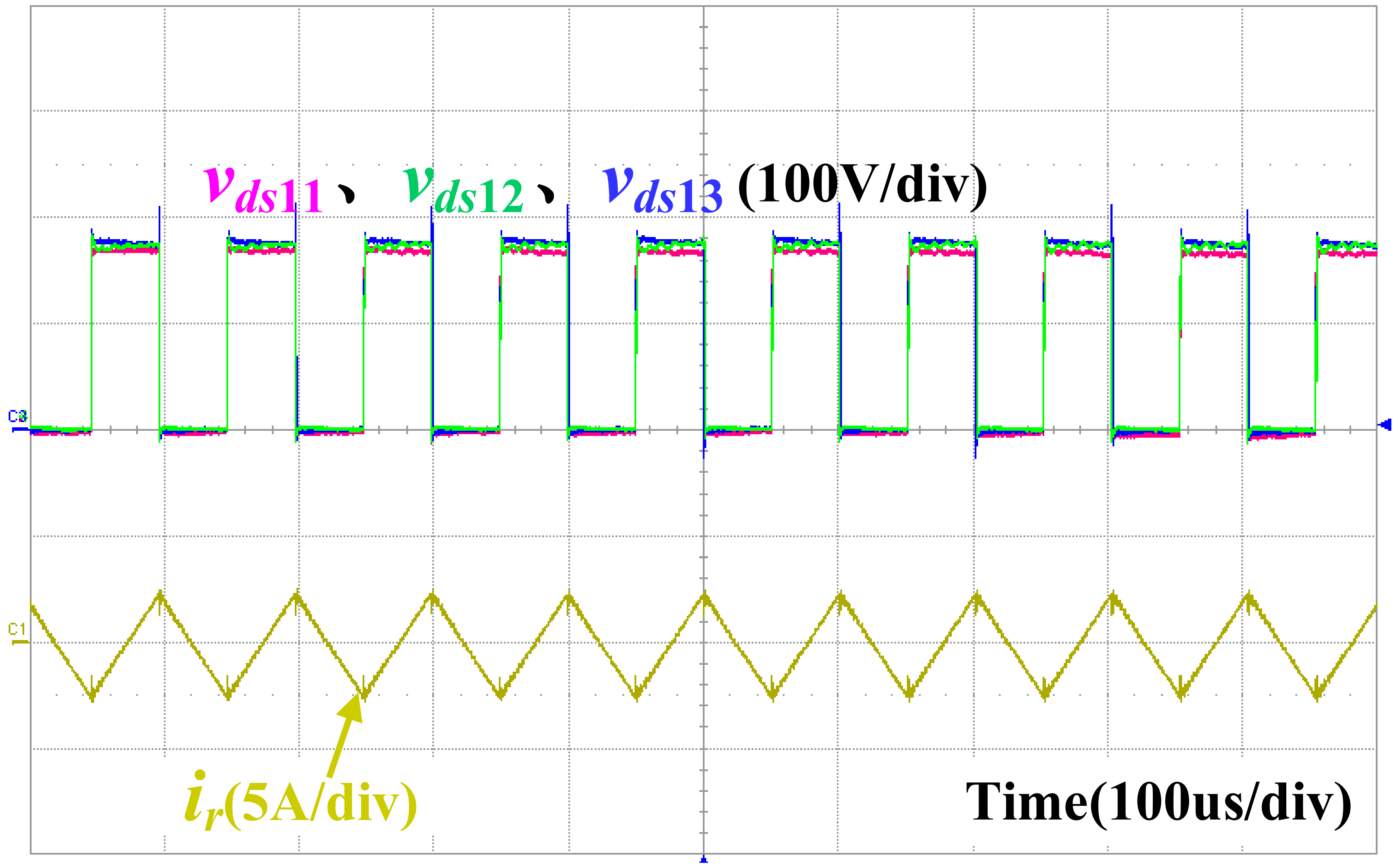




Imbalance degree of series devices < 5%

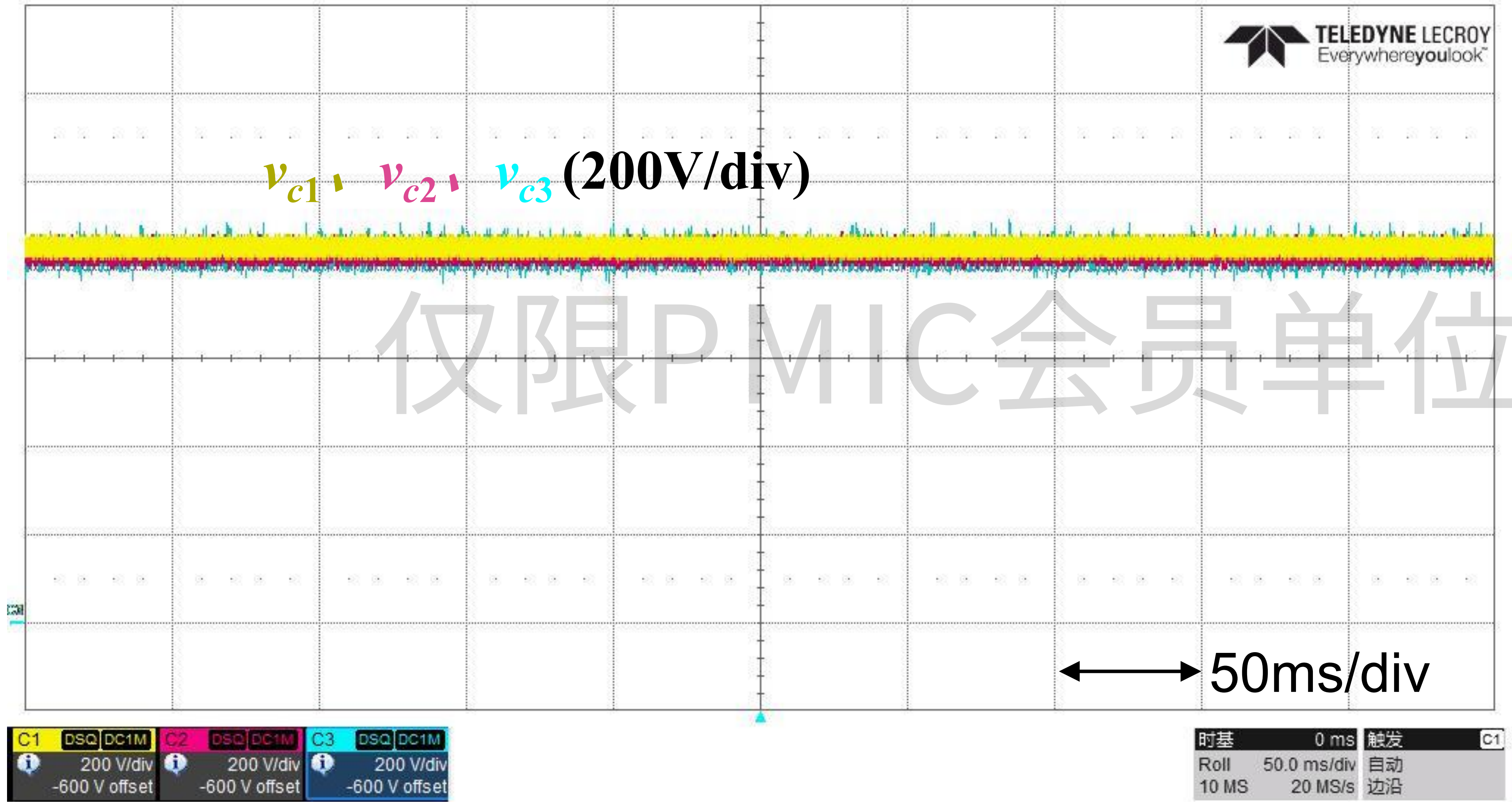
V_i=1kV, No load



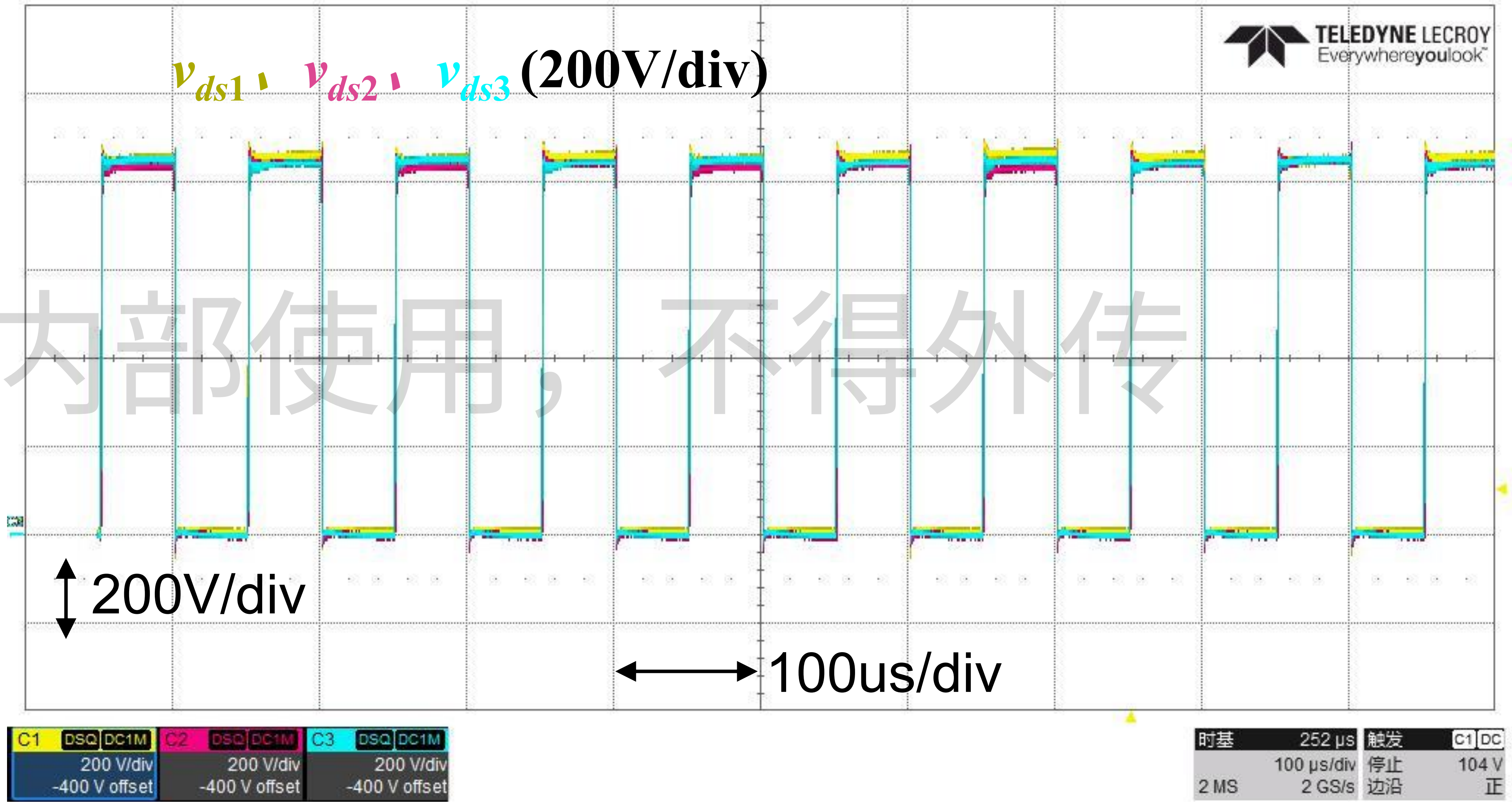


Experimental results @5kV

- **Clamping Capacitor voltage**



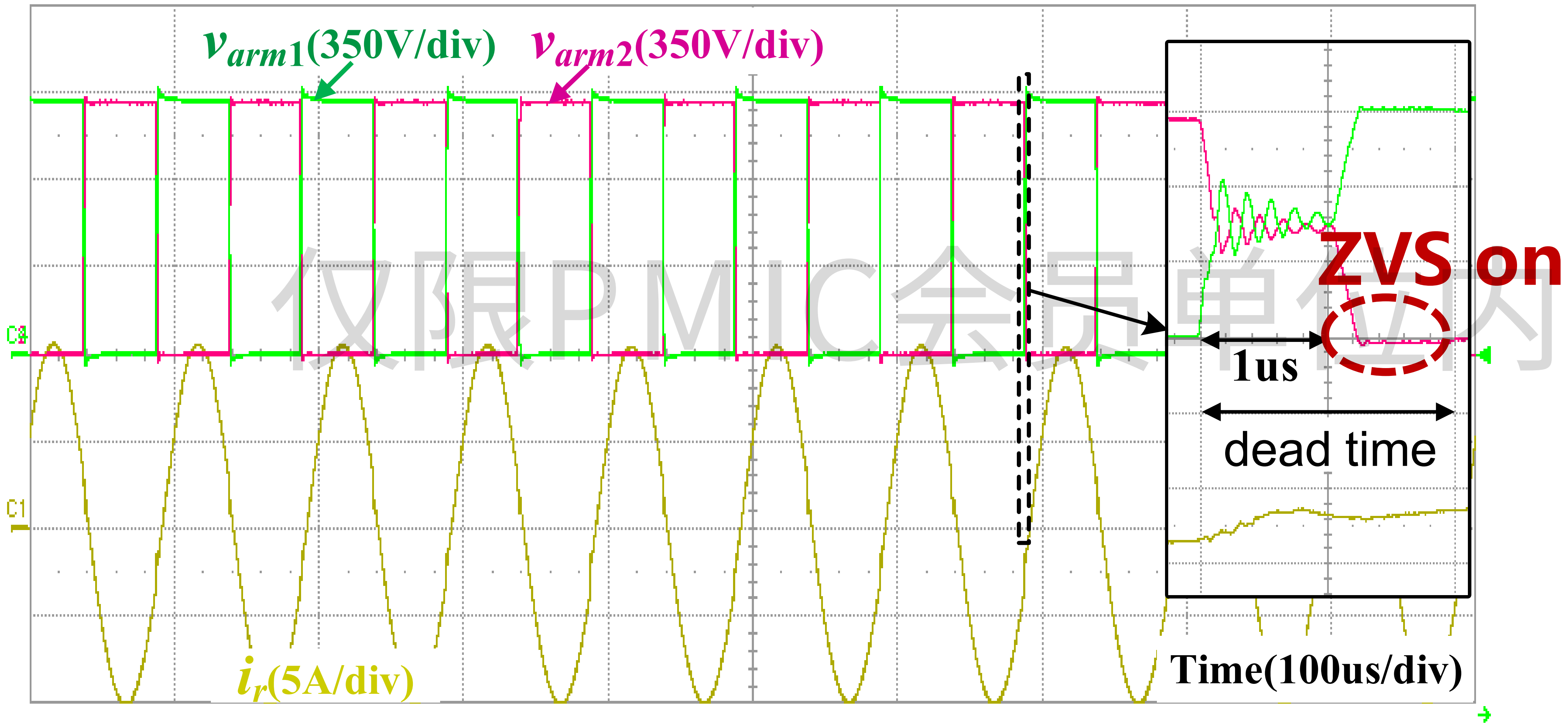
- **Voltage of series-connected SiC MOSFETs**



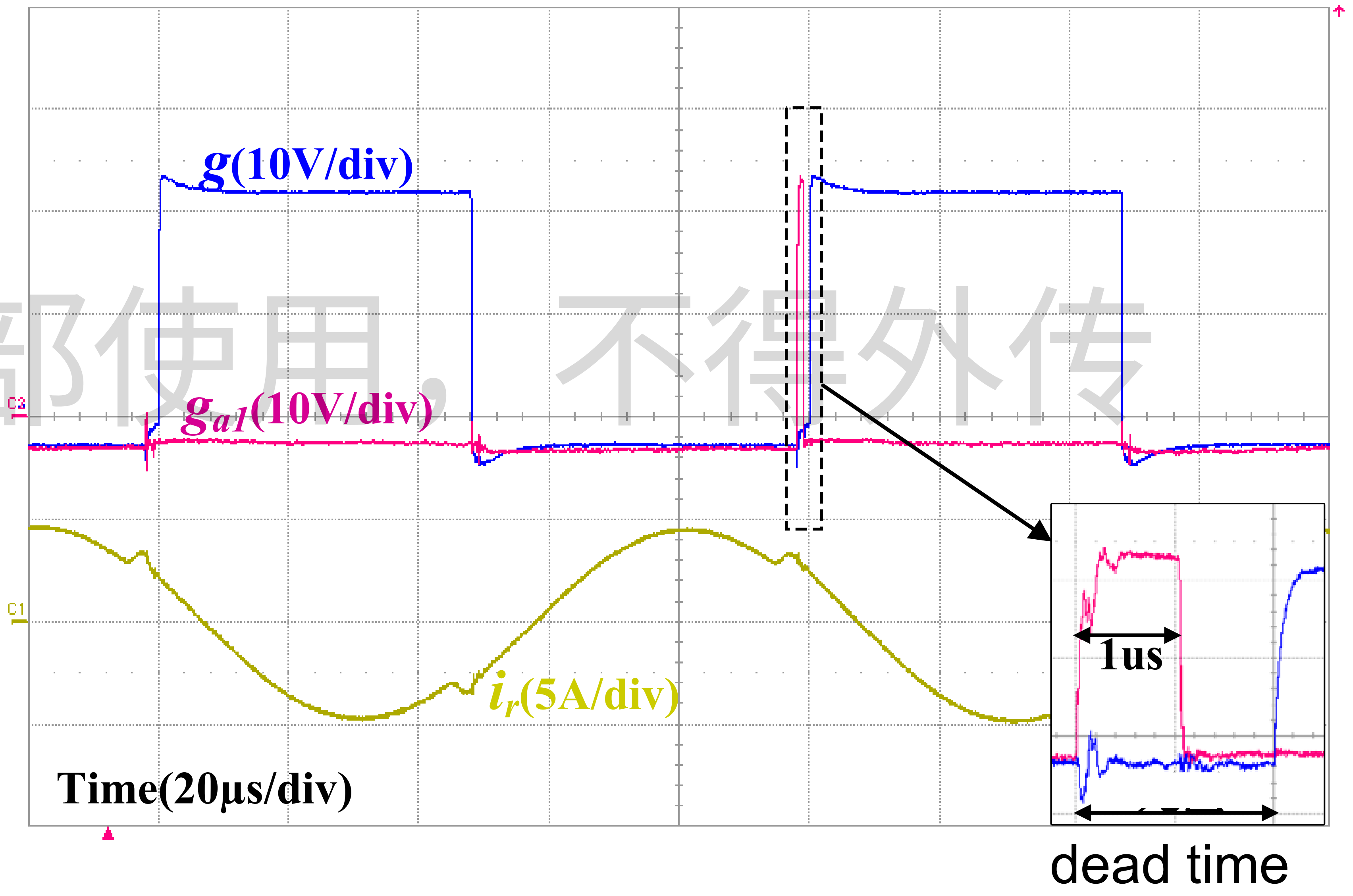
Imbalance degree of series devices **< 5%**

Experimental results

Arm voltages

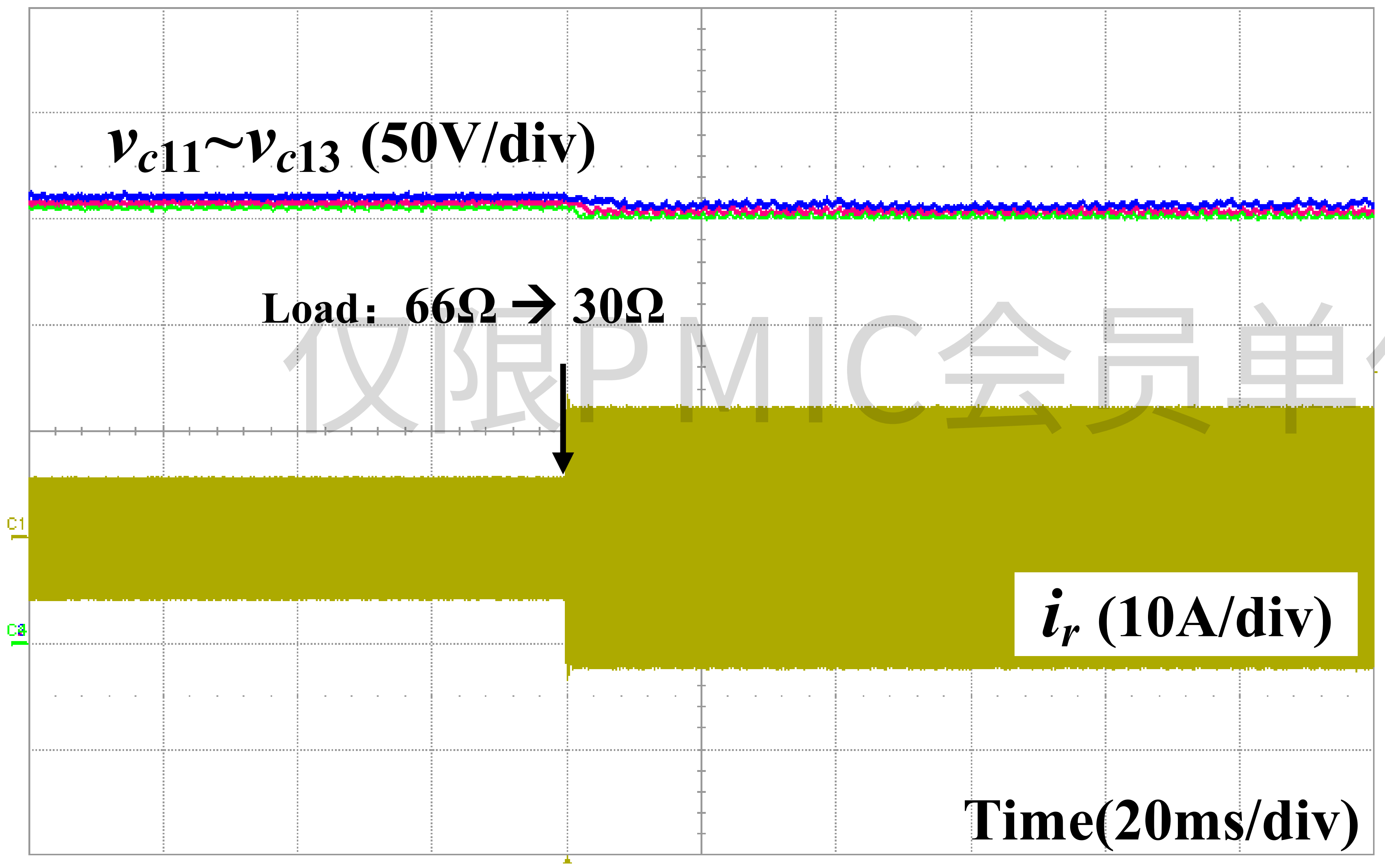


Gate signals

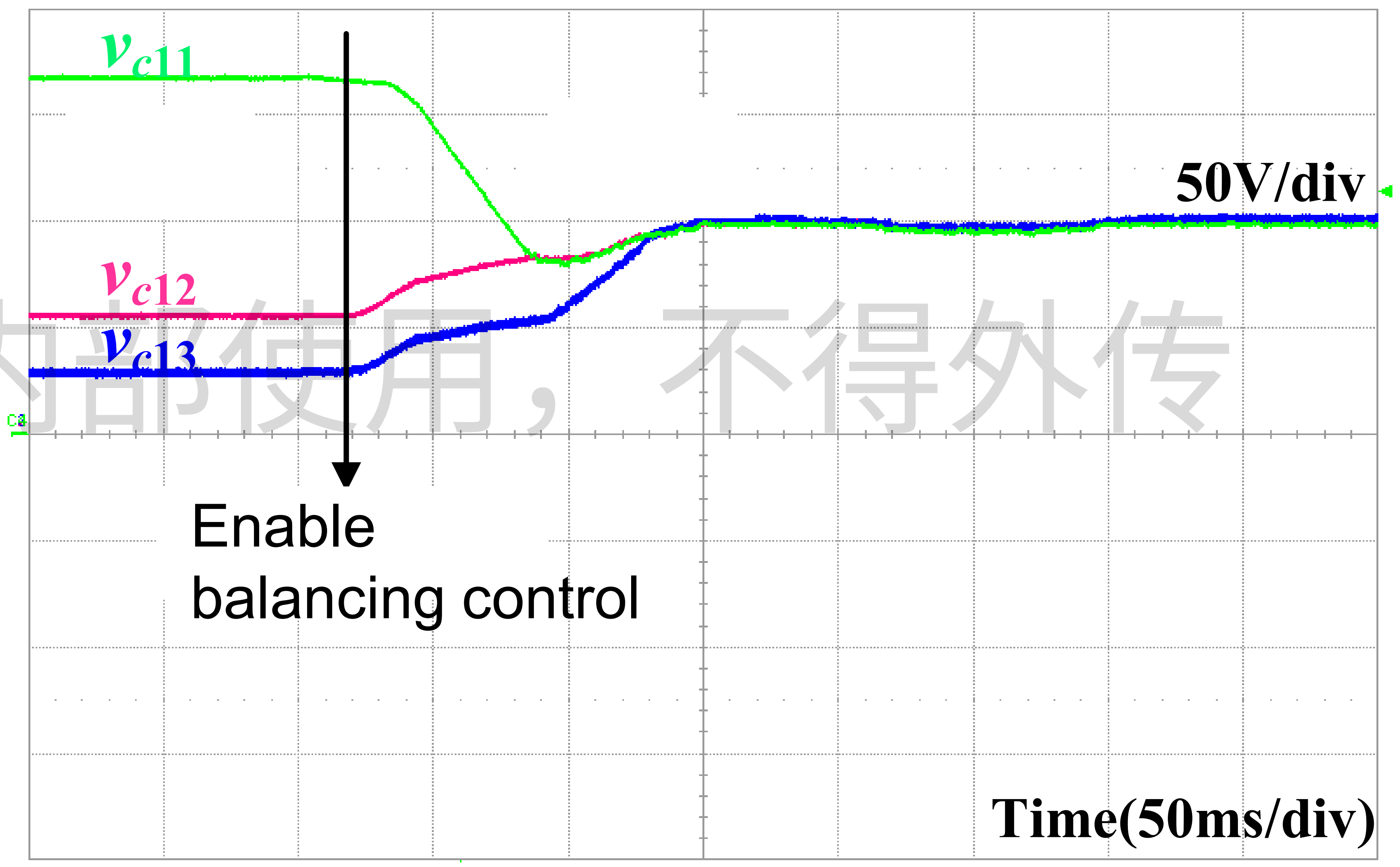


Experimental results

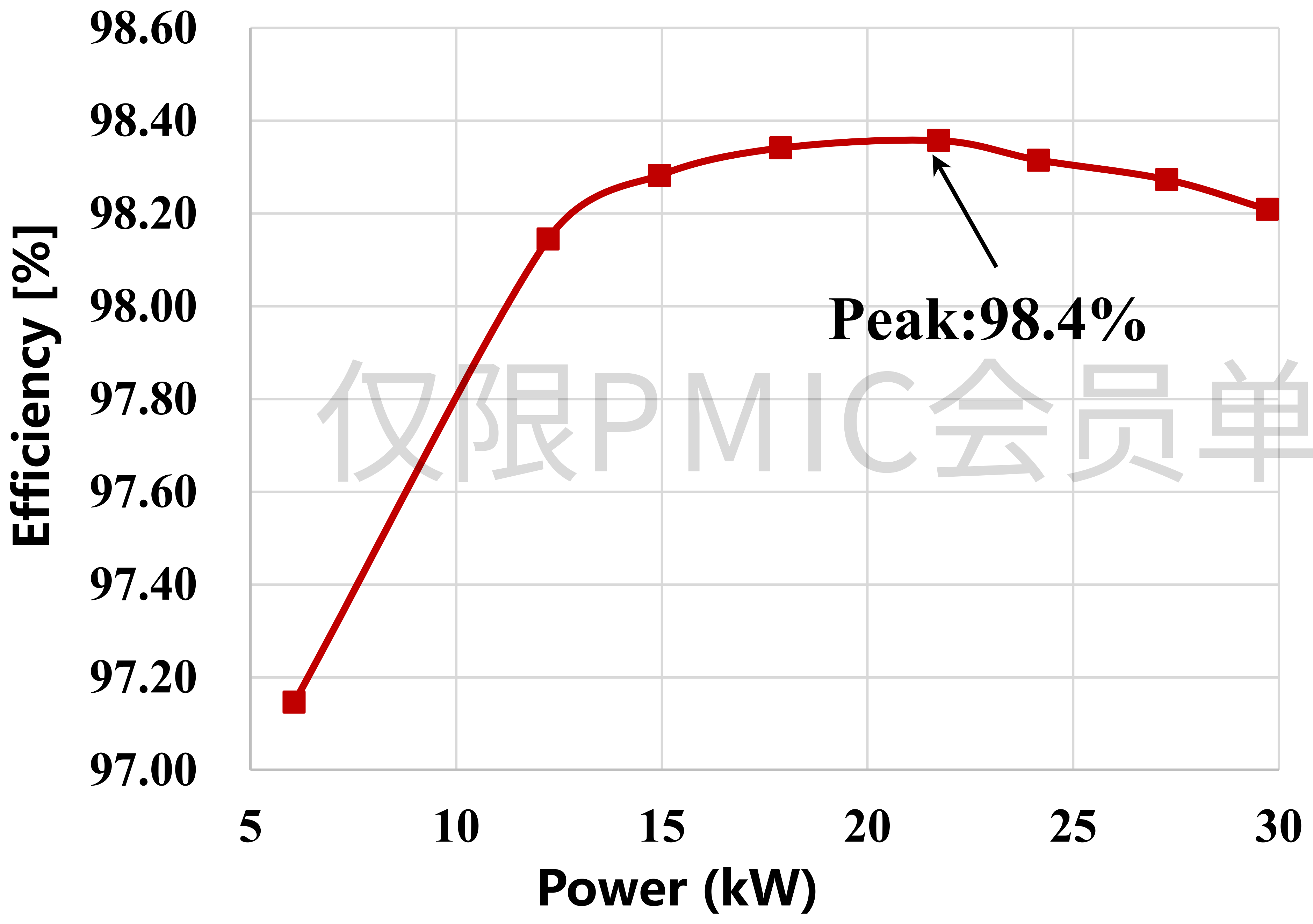
Load change



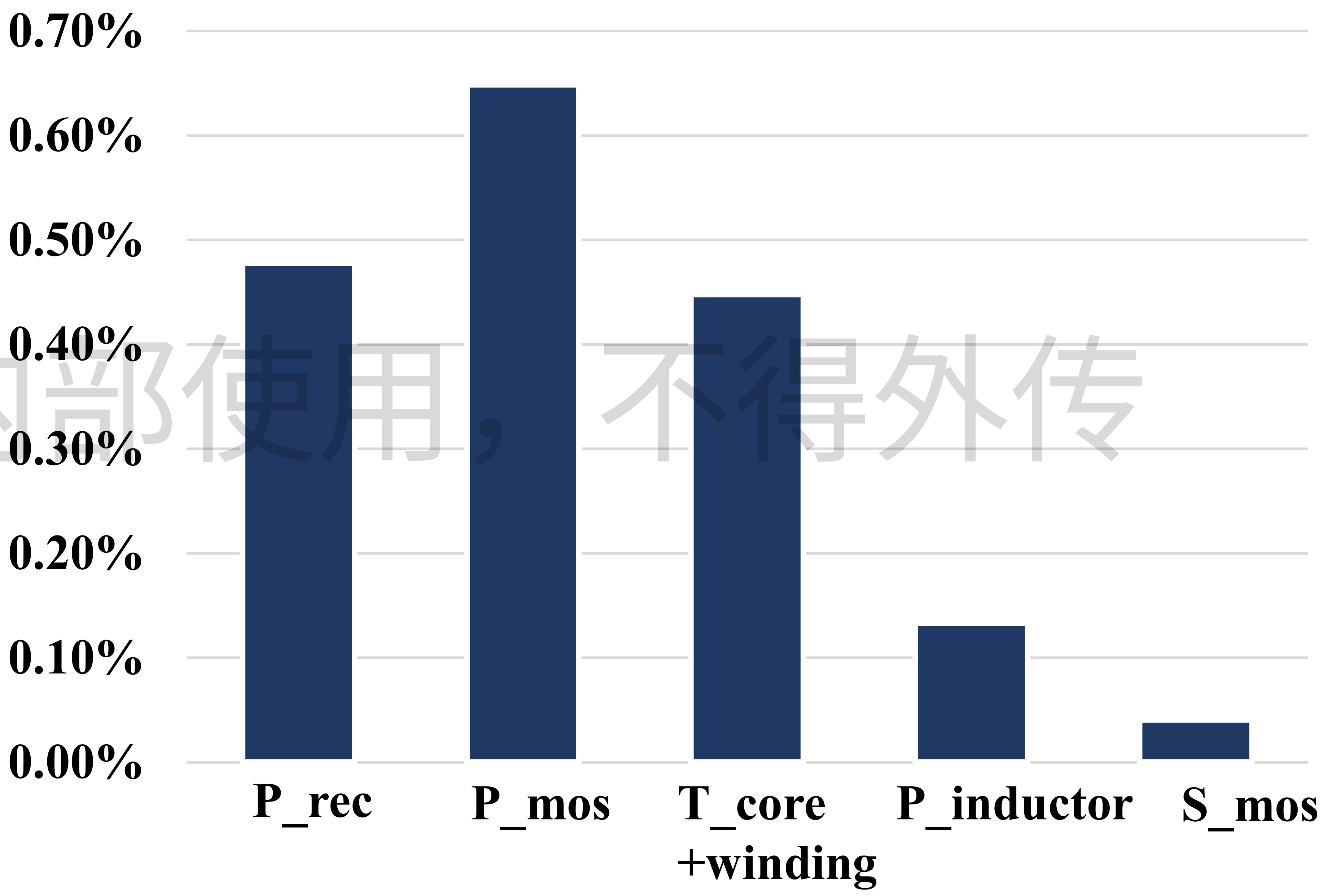
Enable and disable balancing control



Experimental results

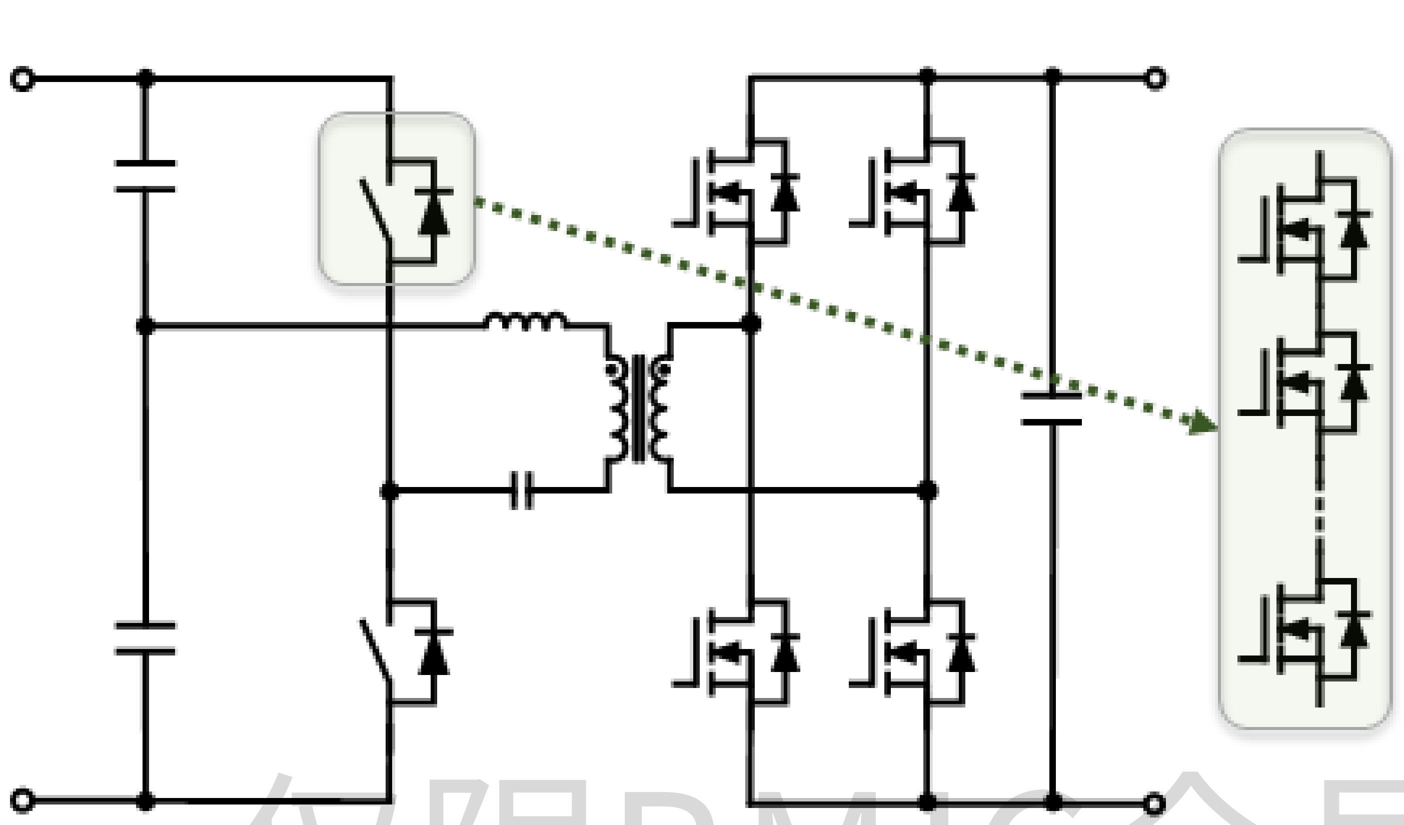


@ 3kV input

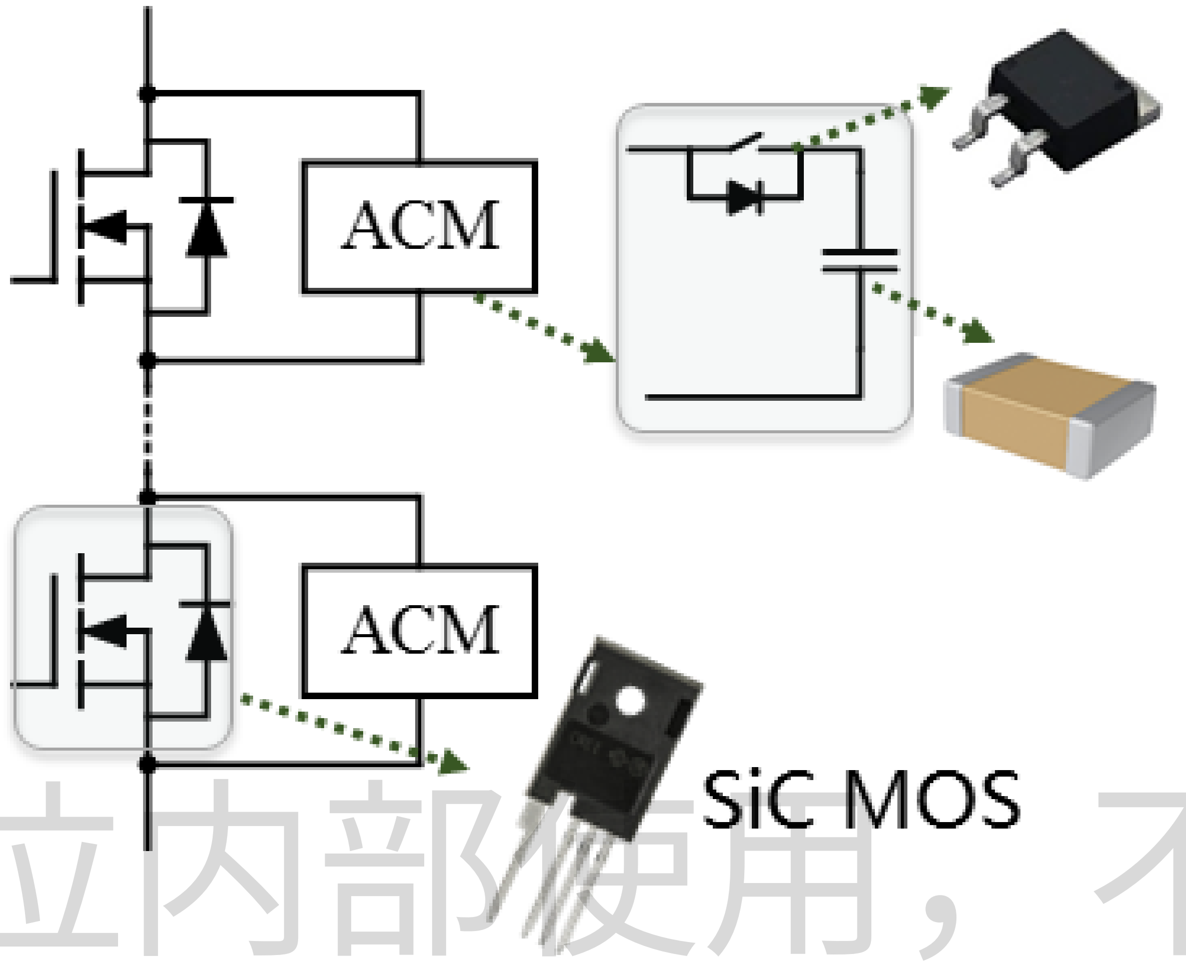


Power loss analysis @ 3kV/30kW

Conclusions



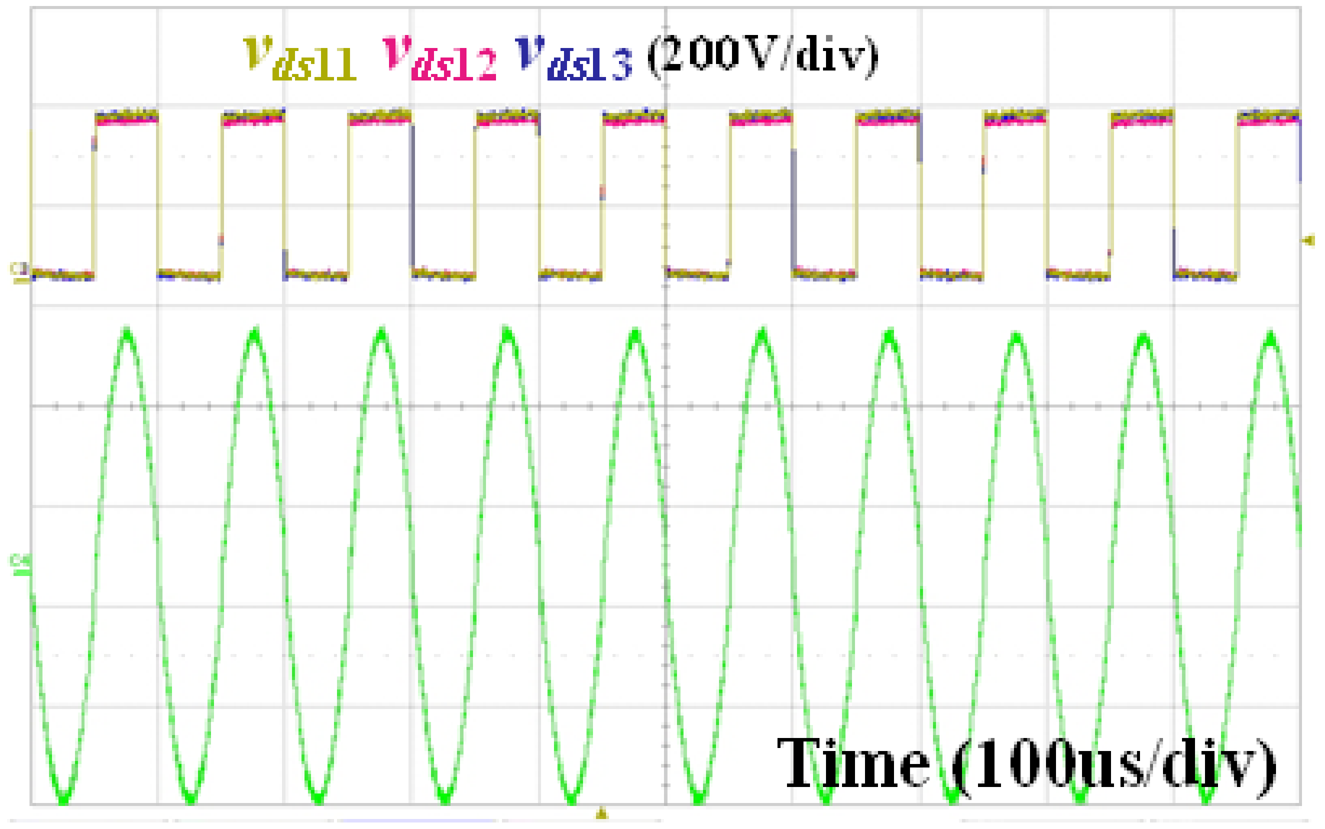
DC Transformer Topology



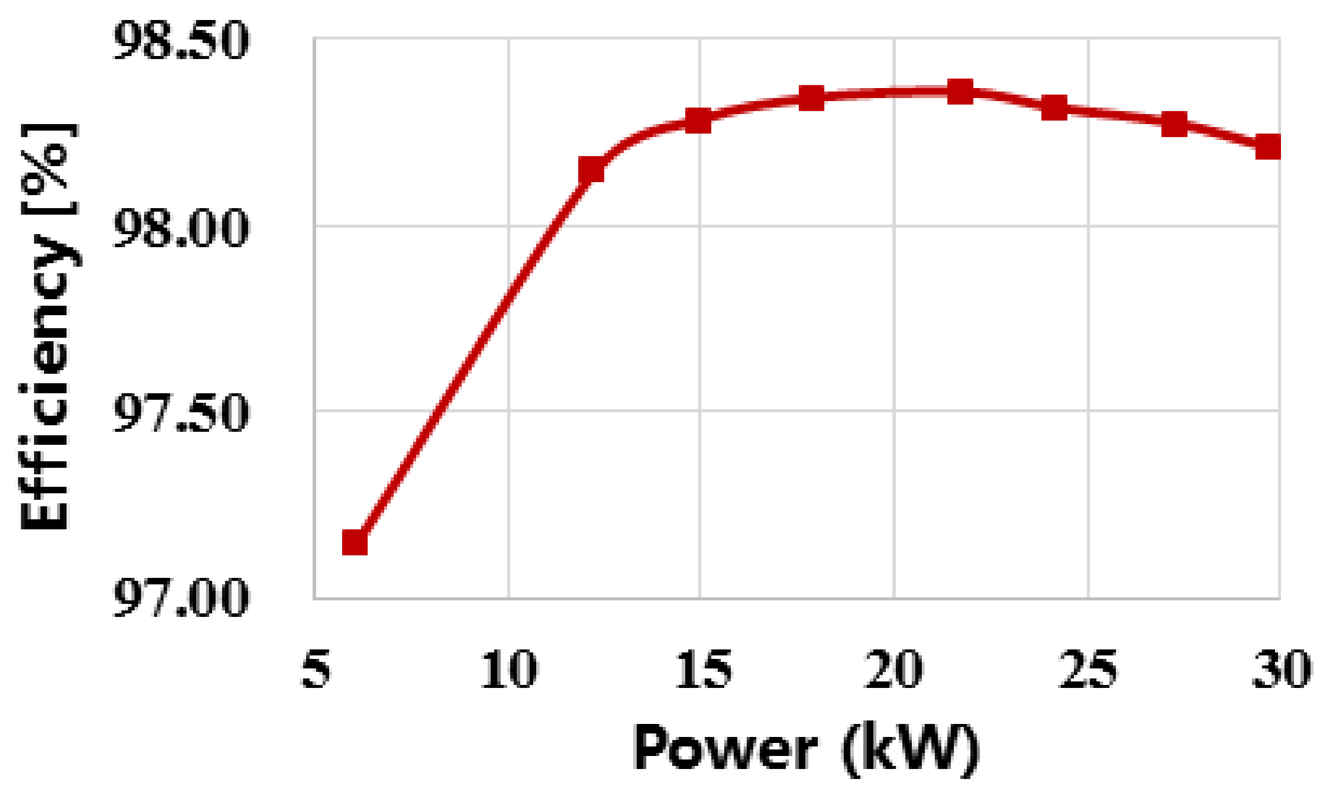
Active clamping balancing circuit

- ✓ No influence on the switching of main device
- ✓ Power loss of the balancing circuit can be ignored

6个SiC MOSFET@10kHz
3kV/750V 30kW



@1kV, 3 devices series-connected
Imbalance degree < 5%



@ 3kV Input

Thank you!

https://person.zju.edu.cn/shaoshuai
shaos@zju.edu.cn